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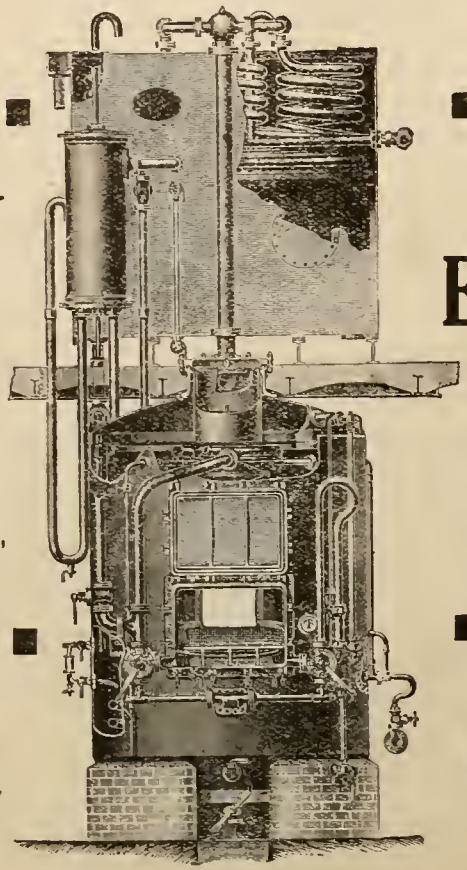

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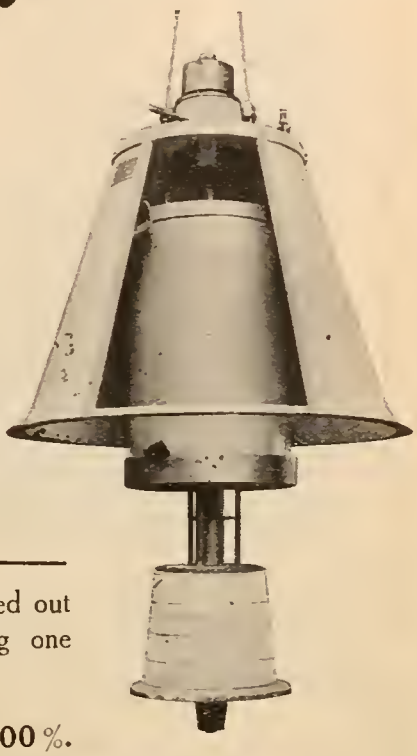

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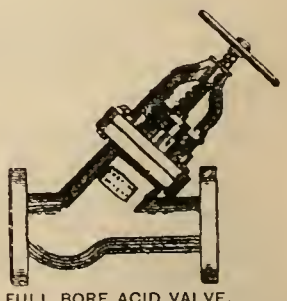

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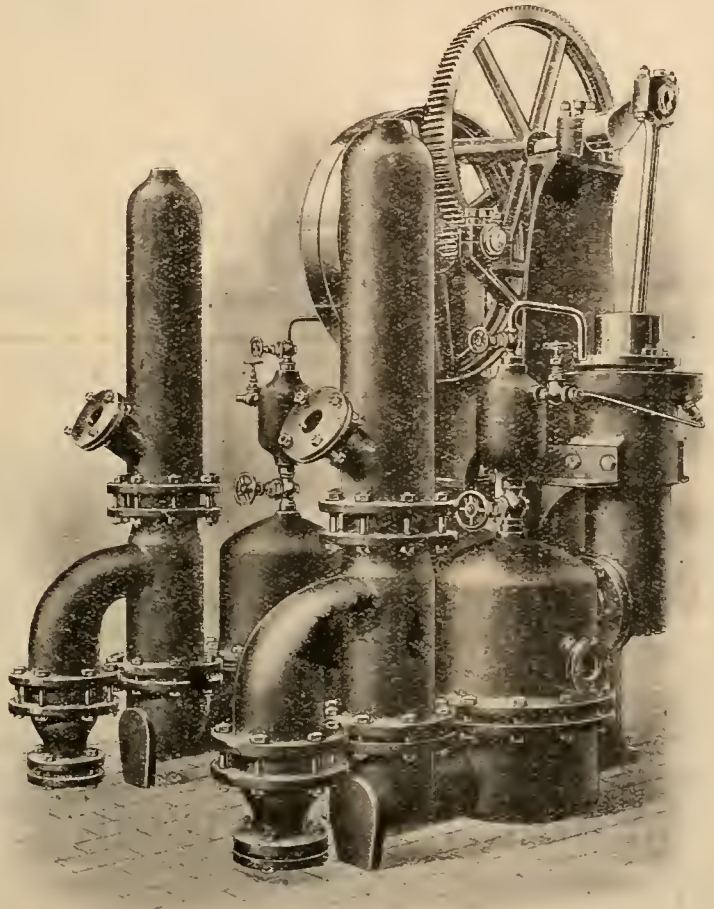

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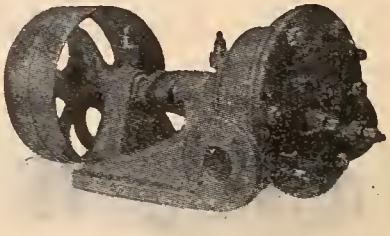

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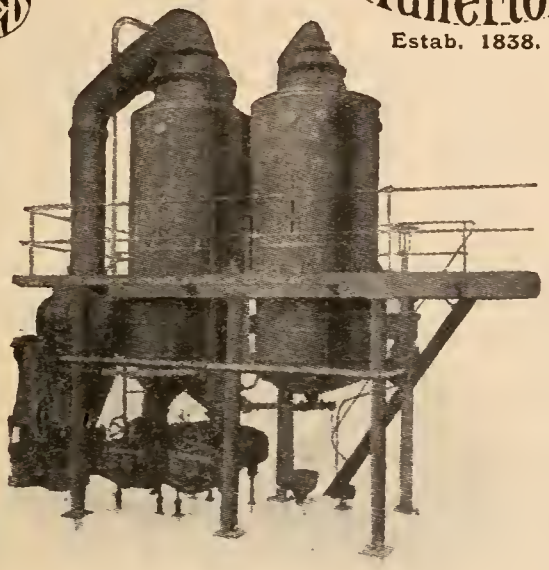

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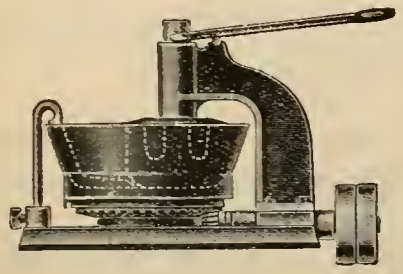

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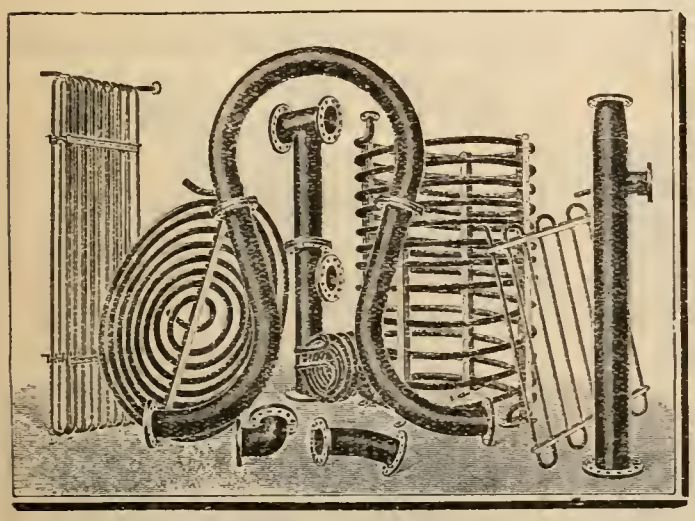

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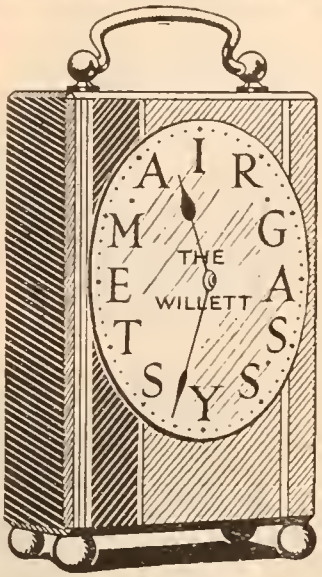

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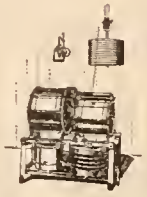

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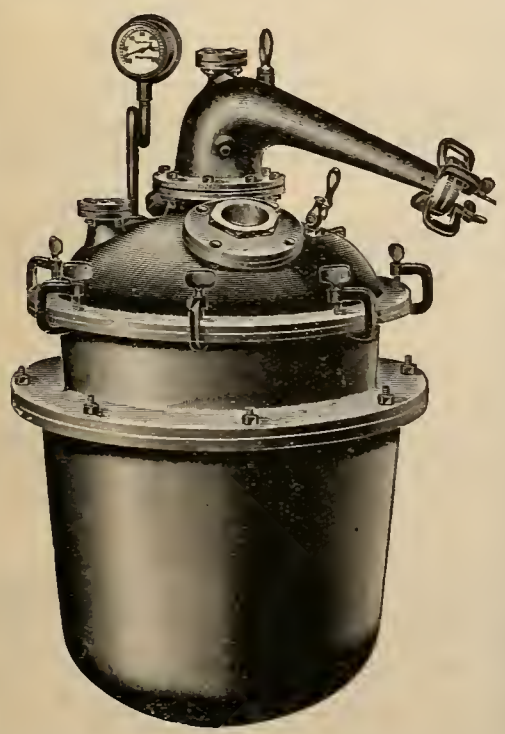

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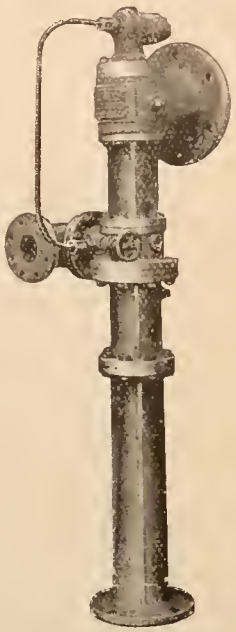

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SOCIETY OF CHEMICAL INDUSTRY

FOUNDED 1881 :: INCORPORATED BY ROYAL CHARTER 1907

CHEMICAL ENGINEERING GROUP

PROCEEDINGS

VOL. I

1919

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PROCEEDINGS

OF THE

CHEMICAL ENGINEERING GROUP

Vol. 1 - 1919

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PROF. J. W. HINCHLEY.

The First Annual Volume of Proceedings of the Chemical Engineering Group of the Society of Chemical Industry

1919

The Chemical Engineering Group is the first of what have been termed "Subject Groups" of the Society of Chemical Industry, *i.e.*, it has as the main purpose of its formation and existence the promotion of the study and the development of the practice of a particular phase of chemical technology, viz., Chemical Engineering, as contrasted with the purely geographical significance of a "Local Section" of the Society. The Society itself, covering as it does in its activities the whole domain of Chemical Technology, can only occasionally, and not at all exclusively and systematically, take account of Chemical Engineering matters, and although in the earlier years of its existence the question of the design and working of chemical plant entered more largely than now (1920) into its deliberations, the enormous amount of chemical discovery effected during the past half-century has almost inevitably resulted in attention being devoted to the examination of possibly useful reactions, processes, and methods, rather than to the development of efficiency in plant for established manufactures. Other factors certainly assisted in bringing about this state of affairs, but there can be no doubt that the most important influence in effecting this change in the character of the Society's discussions during the period referred to has just been stated.

It resulted therefore that at the beginning of the present century the study of Chemical Engineering had fallen somewhat into the background, and to the stress of the European War of 1914—1918 is to be attributed the responsibility for bringing its importance once more into prominence. The reasons for this are given in contemporary accounts of the chemical and explosive manufacturing activities of this country during the period referred to, and will not be further mentioned. A matter of more permanent moment is the attention that was again focussed on the question of chemical plant and its efficient design, construction, and working. It became increasingly evident that studies of plant were, at any rate, equally important with consideration of process—nay, more, *were vital to the successful operation of any process.* In consequence there developed in this country an influential body of opinion in favour of united action towards securing for the study of Chemical Engineering that place in the intellectual life of national industry which its obvious importance demanded.

The guiding hand behind all the activities thereupon set in work was undoubtedly that of Prof. J. W. Hinchley, Wh.Sc., A.R.S.M., F.I.C., Professor of Chemical Engineering in the Department of Chemical Technology of the Imperial College of Science and Technology, London. By his own personal endeavours Prof. Hinchley so stimulated the aspirations towards united effort to which reference has been made that he ultimately felt justified in calling a meeting for discussion of the best form for joint action to take. The meeting was held in London, in the Kaaba Café, King Street, Cheapside, at 8 p.m., on Monday, July 29, 1918, and was attended by about 70 gentlemen interested in various aspects of chemical manufacture and particularly so in the subject of Chemical Engineering. Resolutions, drawn up by Prof. Hinchley, had been circulated to those interested prior to the meeting, and were open for discussion. Dr. G. T. Morgan, F.R.S., Professor of General and Industrial Chemistry in the University of Birmingham, presided, and Mr. H. Talbot, B.Sc., A.R.C.Sc., was appointed by the meeting to act as recorder of the proceedings.

The resolutions as finally carried by the meeting are given below, and differ so little from those originally drafted that the latter are not separately appended:—

1. That a Group be formed for the promotion and study of Chemical Engineering.

2. That a Committee be elected, with full powers to act, to draft rules and to meet the Sub-committee appointed by the Council of the Society of Chemical Industry, with a view to this Group becoming a Section or Group of the Society of Chemical Industry.

3. That the activities of the Group be under the control of a committee and officers elected under rules similar to those of Local Sections of the Society of Chemical Industry.

4. That a special subscription be levied to cover the cost of organisation and work of the Group, and particularly that of printing of papers prior to their being read.

5. That one of the objects of the group be to promote vigorously Chemical Engineering Research.

The meeting thus pledged itself to action in the direction of the formation of some body or organisation which should charge itself with the task of endeavouring to promote the interests of Chemical Engineering and its development on sound and scientific lines in this country, and had expressed

its preference for inclusion in, or affiliation to, the Society of Chemical Industry. As a matter of history, Prof. Hinchley had previously submitted to the Council of the Society a petition, supported by the proper number of signatories requisite for the establishment of a Local Section, for the inauguration of a Chemical Engineering Section of the Society, and a Sub-committee of the Council had been appointed to discuss with Prof. Hinchley and his supporters the suggested relationship between the proposed new organisation and the Society of Chemical Industry. The meeting therefore asked the following gentlemen to associate themselves as a Provisional Committee with Prof. Hinchley (who was to act as Chairman) in all negotiations with the Sub-committee and to carry on the work necessary to give effect to the other resolutions that had been carried:—

E. A. Alliott, Esq. Dr. H. C. Greenwood.
Dr. H. J. Bush. A. J. Liversedge, Esq.
C. S. Garland, Esq. Dr. W. R. Ormandy.
Capt. C. J. Goodwin. F. H. Rogers, Esq.
H. Talbot, Esq. (Hon. Sec.)

The Provisional Committee thus constituted had as a mandate from the meeting the formation of a "Subject Group" or Section of the Society of Chemical Industry for the purpose of promoting the interests of Chemical Engineering. The Committee realised that such a Group or Section would represent a new departure in the Society's activities, and it might even be found impossible, owing to legal difficulties in the wording of the Society's By-laws and/or Charter to give effect to the proposal. Moreover, it was obvious that the 70 or more gentlemen who attended the meeting in London were only a relatively small portion of the total number of those interested in the United Kingdom, and it seemed very desirable to have the considered opinion of these before approaching the Council of the Society with any formal propositions. Accordingly, a memorandum was drawn up by the Provisional Committee (copy of which is given below) and mailed to every member of the Society of Chemical Industry resident in the United Kingdom, along with a covering letter (not reproduced) and a stamped, addressed postcard with a *questionnaire*, with a request for its return, after completion, to the Hon. Secretary of the Provisional Committee.

MEMORANDUM ON THE PROPOSED FORMATION OF A CHEMICAL ENGINEERING GROUP OF THE SOCIETY OF CHEMICAL INDUSTRY.

1. The first steps towards the formation of a Section of the Society of Chemical Industry dealing exclusively with Chemical Engineering subjects were taken by Prof. J. W. Hinchley, Wh.Sc., A.R.S.M., F.I.C., of the Imperial College of Science and Technology, London. Prof. Hinchley, after introducing the subject in a speech at a meeting of the Chemical Industry Club in February, 1918, secured many more than the number of signatures requisite for the presentation to the Council of a formal request for the establishment of a Chemical Engineering Section of the Society, in accordance with the provisions of By-law 40.

2. A petition was presented to the Council asking them to constitute a Chemical Engineering Section of the Society, and in furtherance thereof Prof. Hinchley attended personally before the Council to outline the objects of the members of the Society interested in the Chemical Engineering Scheme.

3. The Council of the Society appointed a Sub-committee to go more fully into the proposals of Prof. Hinchley and his supporters, and, in view of the suggested wider scope of activity of the Chemical Engineering Section as compared with that of an ordinary Section—the functions of such an ordinary Local Section being very specifically defined in the Society's By-laws—the name "Chemical Engineering Group" has been provisionally adopted.

4. Following the appointment of a Council Sub-committee as above, Prof. Hinchley circulated notice of a meeting, to be held in London, to those members of the Society in the United Kingdom who are interested in Chemical Engineering, as shown in the membership list. The meeting was held on July 29, 1918, and was attended by a considerable number of members of the Society and others interested in the scheme, whilst a very large number of letters in support were received from all parts of the country from those unable to be present.

The meeting passed resolutions dealing with the formation of a Chemical Engineering Group of the Society, and a temporary Committee and Honorary Secretary were appointed to crystalliso the suggested aims and objects of the Group into definite propositions. The Committee has held two meetings, and its proposals, including also those of the General Meeting of July 29, are set out in what follows.

5. It is proposed to constitute a "Chemical Engineering Group" as a definite Subject-Section of the Society of Chemical Industry, membership of the Group being open to all members of the Society.

6. The rules governing the conduct of the Group are to be those of a Local Section of the Society, with such alterations as are necessitated by the special character and functions of the Group.

7. The business of the Group is to be conducted by a Committee, with honorary officials, as in the case of a Local Section of the Society. The members of the Committee will comprise 10 elected by the members of the Group as a whole, and Honorary Correspondents, one from each Local Section of the Society of Chemical Industry in the United Kingdom, with the Chairman, Vice-chairman, Secretary, and Treasurer *ex officio*. Honorary Correspondents are to be members of the Group, and each is to be nominated for any Local Section by the Committee of that Local Section to which he is attached.

8. Ordinary meetings of the Group are to include Conferences on special Chemical Engineering topics, these Conferences to be held, at the discretion of the Committee, in centres where the subjects to be discussed have particular local industrial importance. The Conferences will be announced considerably before the time fixed for their occurrence, and papers from experts, not necessarily members of the Society, will be arranged for. Advance copies of the papers are to be circulated prior to the meeting, to enable a profitable discussion to take place. Written remarks on papers from members unable to be present will also be permitted. Full copies of the papers and discussions will constitute the permanent record of the Conference, to be sent to all members of the Group. It is probable that an abstracted account only will appear in the Journal of the Society.

9. To cover the cost of printing and posting of papers prior to the conferences, and of other special activities of the Group, it is proposed to levy a special annual subscription on members of the Group, and payment of this will be a condition of membership.

10. It is intended to arrange Conferences or joint meetings on subjects of mutual interest with other learned societies and to co-operate with them as far as possible so as to avoid duplication of effort in the definition and circulation of knowledge on topics of common concern.

11. It is proposed to develop Chemical Engineering Education and Research as vigorously as possible. The establishment of a Research Fund is contemplated, the Chemical Engineering Group being charged with its allocation and supervision of the work done. In this connexion also co-operation with other societies and institutions will be sought.

12. Summarising, the objects of the proposed organisation are, generally:—

(i.) To advance the cause of Applied Chemical Science;

(ii.) To raise the professional standard among Chemical Engineers;

(iii.) To co-operate with educational institutions for the provision of suitable training for the men who are to enter the profession of Chemical Engineering;

(iv.) To encourage original work in Chemical Engineering;

(v.) To collect and distribute such classified knowledge in Chemical Engineering as shall increase the efficiency and development of industrial activity.

And, specifically,

(vi.) To arrange conferences on special Chemical Engineering topics in accordance with para. 8, above;

(vii.) To establish a Bureau of Information regarding supplies, manufacturers, and plant connected with Chemical Engineering;

(viii.) To draw up specifications of materials used in Chemical Engineering, and to standardise detail fittings;

(ix.) To establish a Technological Library and a Library of Technical Catalogues;

(x.) To establish in London, for the use of country members, an Enquiry Office for referring on specified points to technical literature not easily accessible elsewhere.

(xi.) To establish a Research Fund, in accordance with para. 11, above.

The Provisional Committee, elected at the meeting of July 29th, is constituted as under:—

J. W. Hinchley, Wh.Sc., A.R.S.M., F.I.C., Professor of Chemical Engineering, Imperial College of Science and Technology, London (Chairman).

E. A. Alliott, B.Sc.(Eng.), A.M.I.M.E., Engineer and Chemical Engineer.

H. J. Bush, M.Sc., Ph.D., Chemical Engineer.

C. S. Garland, A.R.C.Sc., B.Sc., A.I.C., Chemical Engineer.

C. J. Goodwin (Capt.), A.C.G.I., B.Sc.(Eng.), A.M.Inst.C.E., Consulting Chemical Engineer.

H. C. Greenwood (Lieut.), D.Sc., F.I.C., Chemical Engineer.

A. J. Liversedge, A.M.Inst.C.E., Consulting Engineer.

W. R. Ormandy, D.Sc., Consulting Chemical Engineer.

F. H. Rogers, A.M.I.M.E., Consulting Engineer and Patent Agent.

H. Talbot, A.R.C.Sc., B.Sc., Chemical Engineer (Hon. Sec.).

15, New Bridge Street, London, E.C. 4.

September 3, 1918.

The *questionnaire* on the post card sent out was as under:—

PROPOSED CHEMICAL ENGINEERING GROUP OF THE SOCIETY OF CHEMICAL INDUSTRY.

1. Are you interested in the development of Chemical Engineering?.....
2. Are you in favour of the formation of a Chemical Engineering Group or Section of the Society of Chemical Industry?.....
3. Would you prefer that a separate organisation—*e.g.*, an Institute of Chemical Engineers—be formed?.....

3A. Are you in favour of the formation of a separate organisation as in (3) above in the event of failure, on account of legal or other difficulties, to establish a Group or Section of the Society of Chemical Industry?.....

4. Would you become a member of either organisation in (2) or (3) above?.....

Name..... *Address*.....

Profession..... .....

Over 2500 letters and enclosures as above specified were sent out during August and September, 1918, to members of the Society in the United Kingdom, and nearly 800 replies were received. Of these over 85% were definitely in favour of the establishment of such a Chemical Engineering organisation as was proposed, and intimated preference for its formation as a Section of the Society of Chemical Industry; 75% of the replies favoured the inauguration of a separate Institution of Chemical Engineers if any difficulty were experienced in securing inclusion in, or affiliation with, the Society of Chemical Industry. The Provisional Committee also sent out to the Committee and Honorary Secretaries of all the Local Sections in the U.K. invitations to hold meetings of their Sections to consider the suggested scheme, and conferences of this kind were called and addressed by different members of the Provisional Committee at Glasgow, Liverpool, Manchester, and Birmingham during September and October, 1918.

The Provisional Committee thereupon met the Council Sub-committee on the Proposed Chemical Engineering Group on October 4, 1918, and the proposals which had been circulated in the aforementioned memorandum, along with suggested rules for the Group which had been drafted by the Provisional Committee, were jointly discussed. The Council Sub-committee agreed to all the suggestions of the Provisional Committee with slight alterations, making membership of the proposed Group open to any member of the Society, wherever resident, and ensuring for the Society prior right of publication of matter prepared for issue under the auspices of the Group. A recommendation that the Chemical Engineering Group be provisionally recognised was made to the Council of the Society by the Sub-committee, and formal agreement to its establishment as a Subject Group of the Society was given by the Council at the meeting of October 24, 1918. Thereafter the Council Sub-committee and two co-opted members of the Provisional Committee of the Group revised and amended the draft rules of the Group and made alterations in the By-laws of the Society to permit of the formation of Subject Groups under its control and supervision.

The Rules of the Chemical Engineering Group were approved by the Council of the Society at the meeting of April 30, 1919, and the suggested altera-

tions in the By-laws, as affecting the establishment and representation on the Council of Subject Groups, were handed over to the then-existing By-laws Sub-committee of the Council, which was to report to the Annual General Meeting of 1920. The Chemical Engineering Group thus became formally established and recognised as an integral part of the Society of Chemical Industry, open to any member of the Society, no matter where resident, on payment of the annual Group subscription, and had, at the close of 1919, 510 members on its roll.

The Committee and Officers of the Group for 1919, elected at the Inaugural Meeting held at the Abercorn Rooms, London, E.C. 2, on Friday, March 21, 1919, and subsequently, are given below:—

Chairman: Prof. J. W. Hinchley, Wh.Sc., A.R.S.M., F.I.C.

Vice-Chairman: E. F. Armstrong, D.Sc., F.R.S., F.C.G.I., F.I.C.

Hon. Treasurer: *F. H. Rogers, M.I.M.E.

Hon. Secretary: *H. Talbot, A.R.C.Sc., B.Sc.

*E. A. Alliott, B.Sc.(Eng.), A.M.I.M.E.

*H. J. Bush, M.Sc., Ph.D.

*C. S. Garland, A.R.C.Sc., B.Sc., F.I.G.

*Capt. C. J. Goodwin, A.C.G.I., B.Sc. (Eng.), A.M.Inst.C.E.

*†H. C. Greenwood, D.Sc., F.I.C.

H. Griffiths, A.R.C.Sc., B.Sc.

E. Hill, A.R.C.Sc., F.I.C., D.Sc.

H. F. V. Little, A.R.C.Sc., B.Sc., D.I.C.

*A. J. Liversedge, A.M.Inst.C.E.

*W. R. Ormandy, D.Sc., F.I.C., M.I.Pet.Tech.

J. Arthur Reavell, M.I.M.E.

Honorary Correspondents or Local Sectional Representatives.

Birmingham.—J. C. Sheldon, Ivy Cottage, New Oscott, Erdington, Birmingham.

Bristol.—E. Walls, The Garthe, Percival Road, Clifton, Bristol.

Edinburgh.—J. W. Romanes, B.Sc., Lothian Chemical Co., 3, Broughton Road, Edinburgh.

Glasgow.—W. H. Coleman, 1, Athole Gardens, Newlands, Glasgow.

Liverpool.—A. Holt, M.A., D.Sc., F.I.C., The University, Liverpool.

London.—A. E. Berry, Boake, Roberts and Co., Carpenter's Road, Stratford, E. 15.

Manchester.—Howard Cheetham, 18, St. Ann Street, Manchester.

Nottingham.—E. P. Hedley, A.R.C.Sc., Ph.D., A.I.C., 1, Chesterfield Villas, Victoria Avenue, Ockbrook, nr. Derby.

Representatives for Newcastle and Leeds have yet to be appointed.

H. Talbot,
Honorary Secretary.

24, Buckingham Street,
Strand, London, W.C. 2.
January, 1920.

* Signifies member of the Provisional Committee.
† Died Nov. 4, 1919.

FIRST CONFERENCE.

POWER PLANT IN CHEMICAL WORKS.

LONDON, JULY 16, 1919.

The first Conference was held at the Salters' Hall on Wednesday, July 16, 1919, the chair being occupied by the President, Prof. Henry Louis.

The PRESIDENT expressed his great pleasure at being able to open the proceedings of the first Conference of the newly-founded Chemical Engineering Group of the Society, which was setting such an excellent example of energy and activity. The work of the Conference was of exceptional interest and came at a psychological moment. In a sense, practically all the work of the Conference was devoted, directly or indirectly, to problems of fuel economy. All who were connected with engineering work in any form whatever were aware of the extreme importance from the technical and commercial point of view of exercising the utmost economy in the use of fuel. Possibly in this country we had not been as careful in that respect as we might have been. He had heard it said that one of our difficulties had been that coal had been too cheap, and consequently we had not treated it with that respect which it deserved. He did not think that reproach would be uttered any more in the future. We were faced not only with a great increase in the price of fuel—that might not be an unmixed evil—but we were face to face with a very serious diminution in the output of coal, and that, on the contrary, was a subject of the utmost gravity. Coal was the only material for export in any quantity that we possessed in this country, and it was only by the utilisation of that raw material that this country could live. The production of coal, therefore, was of the greatest and most vital importance to the whole nation. It was only quite recently that the public had been rudely awakened to the fact that our coal production was falling off seriously. As usual, the British public never saw any trouble coming until it had come. Those who had been in close touch with coal mining had seen this coming for many years. Many of them had said, and had had no hesitation in saying, that the moment the Minimum Wage Act was introduced the coal production would necessarily fall off. Facts had borne out only too accurately the truth of that prophecy, and with every successive increase in the minimum wage there had been a corresponding diminution in output. As far as he remembered, the coal mining industry was the only industry of any importance that had a definitely fixed minimum wage, and in the same way the coal mining industry was the only industry of any importance in which the output per man engaged had been steadily falling off. When faced with these definite facts, it was difficult to avoid the definite conclusion to which they pointed, and he personally was convinced that the low outputs to-day were due to the high minimum wage and to the fact that whether a man worked or not he got his pay. A Durham pitman's explanation of the minimum wage was that it was what they received for going down the pit, and if they wanted any more they must work for it. Many of the miners were quite satisfied with the minimum wage, and as long as that position remained we should be faced with low production. It was the duty of these in the chemical industry to make the best of these conditions, and to see that be the output great or small, it was utilised to the utmost fraction. That was a big problem, and it was essentially one to which their discussions at the Conference would be devoted. He therefore looked upon the Conference as of importance not only to the chemical industry but to the industries of the nation at large. They had met under very favourable auspices by the kindness of the Salters' Company, one of the ancient City Guilds, who had so kindly placed their magnificent building at the disposal of the Society. These Guilds were Associations of men engaged in some particular branch of commerce or industry who met together and worked together for the common good of the particular industry with which they were concerned. They were perhaps the most democratic institutions that could be imagined. Every craftsman had had a free voice in the conduct of their affairs; in the early days of the Guilds industry was not dominated by a comparatively small caucus, but the entire industry freely and democratically discussed their action for their common good. In many senses these Guilds were the predecessors of our modern Trades Unions, but there was one essential difference—the Guilds punished a man and fined him if he did bad work or did too little work, whilst the Trades Unions fined a man if he did too much! Until the Trades Unions could take a lesson from the old Guilds and act on broad, honest, democratic lines, we were certain to have difficulties. He believed, however, that gradually and slowly the lesson would penetrate through all ranks in the country. We could not help seeing that the greatness of Britain had been built up by the industries which the old Gnilds had erected, and if we wanted to maintain our industries on the footing to which they had been brought by the Guilds we should have to work on similar lines to the Guilds. These two points were necessarily most closely connected. It all came back to the same thing, that if we wanted to maintain our position as a nation we must produce to the utmost of our capacity, and we must utilise what we produced to the very best possible advantage. The first part of the problem was essentially a problem of the worker; the second part of the problem was essentially a problem for the scientist. They had met to discuss that particular aspect of the question, and all the papers which were to be read tended directly or indirectly in that direction. In opening the first Conference of the Chemical Engineering Group he could not do better than call upon one who had had a high reputation for many years as a chemical engineer, and who had shown how to economise and utilise fuel to very great advantage, *viz.*, M. Paul Kestner.

M. PAUL KESTNER said that if his career had been successful it was because of the kind welcome he received in his early days when he used to come to this country as an inventor; he received more assistance and help in this country than anywhere else. One often heard that the English were reserved and conservative, but so far as he personally was concerned he could prove that that was not the fact. With regard to the work of the Group, what would the chemical industry be without chemical engineering? It could be said that the first page of the history of the chemical industry

had been written in England. It had had its origin in this country, and yet it was surprising that when English people wrote about chemical engineering matters they very often forgot the names of Englishmen who had helped to found the industry. For instance, the name of Howard, the inventor of the vacuum pan, was most familiar abroad, and yet it was almost totally unknown in England. He was very glad to be present at the opening of this first Conference, to see that chemical engineering was regarded as an important science, and also to wish the new Section of the Society of Chemical Industry every prosperity.

The PRESIDENT then called upon Captain Goodwin to read his paper on "Waste-heat Boilers and Pulverised Fuel in Chemical Factories."

WASTE-HEAT BOILERS AND PULVERISED FUEL IN CHEMICAL FACTORIES.

BY C. J. GOODWIN, A.C.G.I., A.M.INST.C.E., B.SC.

Efficient utilisation of fuel of every kind is an obvious national necessity, and while fuel costs are not always a vital item in the manufactured cost of chemical products, no apology is necessary for examining the possibilities of waste-heat boilers and pulverised fuel in chemical factories. Of their application to steelworks, metallurgical plant, cement works and power stations, much has been written; pulverised fuel in particular is attracting full attention and a report by Mr. L. C. Harvey is shortly to be published under Government auspices descriptive of latest American practice.*

The adoption of scientific and properly proved devices for the reduction of waste is one method of securing higher economy and waste-heat boilers are selected merely as an example; the other method, increase in primary efficiency, is exemplified by the application of pulverised fuel.

Chemical engineers derive neither satisfaction nor profit from general descriptions and comparisons of plant and processes nor would there be room for them in this contribution, but an abbreviated bibliography regarding pulverised fuel is appended for the use of those who desire to study the subject in greater detail.

Part I. Waste-heat boilers.

The waste heat of factory chimneys is often partly recovered in Green or other economisers, while for puddling and other metallurgical furnaces waste-heat boilers are being increasingly adopted. The heat from the exhausts of internal combustion engines has, however, frequently been allowed to go to waste, while in chemical factories that in the gases from lime kilns, fusion pots, roasting, reverberatory and other furnaces is but rarely utilised.

The recoverable heat in such "waste" gases depends not only on their temperature, but on their average specific heat and the reduction in temperature which is permissible before corrosion occurs. Furnace gases usually consist mainly of oxygen, nitrogen, carbon monoxide, and carbon dioxide, the specific heat of the first three being 0·308 cal. per cb.m.; aqueous vapour may be taken as 0·365 and carbon dioxide 0·411 cal. per cb.m. These figures are fairly corrrect at about 200° C. and are sufficiently accurate for the temperatures usually obtaining in waste-heat boilers. The available heat from open hearth steel furnaces has been calculated in a different way and very completely by T. B. Mackenzie, who also deals with the theoretical considerations underlying the design of waste-heat boilers,† but otherwise the literature in connection with this subject seems almost non-existent.

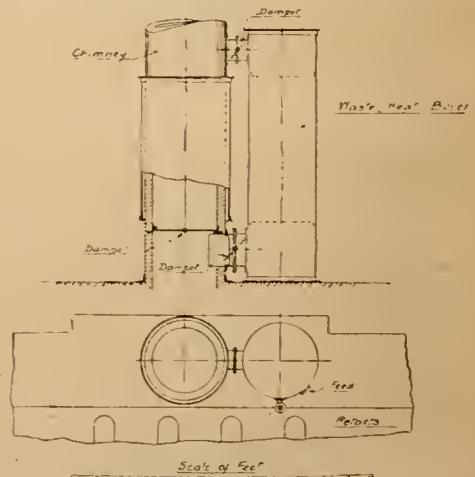
The heat in calories, H, available per minute may be expressed by the equation

$$H = S \times Q(T_1 - T_2).$$

S is the average specific heat of the gases in calories per cubic metre; 0·32 may be taken as an average figure in most cases. Q is the quantity of gas in cb.m. per minute, T_1 and T_2 are the initial and final temperatures of the gases in ° C.

If in any particular case it is possible to reduce the temperature of the gases below 100° C. a small allowance must be made for the latent heat of vaporisation of the moisture present, which then becomes available. This is possible when the gases leaving the boiler pass through a feed-water heater; to permit of this, induced draught is usually necessary, and every precaution must be taken to avoid excessive corrosion in the feed-water heater owing to the low exit temperature of the gases.

As an example from the author's experience, we may take the case of a lime kiln from which 60 cub. metres per minute of gases were discharged at an average temperature of 525° C. As a certain amount of sulphur dioxide was present, it was not thought advisable in the first instance to reduce the temperature of the gases below 210° C., or about 40° C. above the temperature of the steam to be generated. The available heat was $H = 0{\cdot}31 \times 60 \times (525 - 210) = 5859$ calories (23,300 B.Th.U.) per minute. The carbon dioxide in the gases is used in the electrolytic manufacture of sodium carbonate and chlorine, and artificial cooling was necessary before it could be passed into the cells. By passing the gases through a waste-heat boiler having a thermal efficiency of 60% and allowing 7½% for radiation losses, 1700 lb. of steam per hour from and at 100° C. would be generated at a pressure not exceeding 100 lb. per square inch, and the cost of artificial cooling saved. The present cost of installing such a boiler, exclusive of pipework etc., would be about £500.



Waste-heat Boiler for set of four continuous Vertical Gas Retorts.

FIG. 1.

The gas and coke oven industries are probably the principal users of fuel in the chemical industry, and it seems surprising that so little has been done in the past to utilise fully the available heat in suitable cases. In gas works coke is no longer a drug upon the market, and steam is required for producers and various processes. In these and in coke-oven plant working regeneratively the objection may be raised that if any more heat is taken out of the gases their temperature would be in-

* "Pulverised coal systems in America." Special Report No. 1. Fuel Research Board. H.M. Stationery Office. Price 2s. 6d. net. (Published since this paper was written; see J.S.C.I., 1919, 190R).

† J. Iron and Steel Inst., **98**, 319–348.

sufficient to maintain a proper draught; induced draught would overcome this objection, and, given suitable conditions for utilising the steam, waste-heat boilers should be quite remunerative after allowing for the power required to drive the fans.

Fig. 1 shows one possible arrangement of a waste-heat boiler designed by the Bonecourt Waste Heat Boiler Co., Ltd., and ordered as a trial installation for a standard set of continuous vertical retorts working under natural draught. It will be noticed that by adjustment of the dampers the volume of gas passing through the boiler can be adjusted to correspond with working requirements. The gases enter the boiler at 700° C. and are purposely designed to leave at 300° C. in order to leave sufficient draught in the chimney; a better utilisation of the gases would be possible by using induced draught. A boiler working with the waste gases from a single retort "setting" will give 500 lb. of steam per hour at 100 lb. pressure, so that a gas works comprising, say, 60 retorts could raise 7500 lb. of steam per hour from and at 100° C. in return for a capital outlay of about £4000 and with relatively small operating costs. When the enormous number of gas retorts, coke ovens, and also future low-temperature distillation plants are considered, it is evident that waste-heat boilers should be increasingly adopted in such works and in connexion with utilisation of sensible heat in gases produced by the super-power stations and by-product works of the future.

Taking the case of a gas engine, tests made by the Institution of Civil Engineers show that at full load about 38% of the total available heat in the gas is exhausted into the atmosphere and about 30% lost in the water jacket and by radiation. Taking a 1000 b.p. gas engine, the equivalent full load steam production based on 60% thermal boiler efficiency is 2250 lb. of steam per hour, equivalent to about 280 lb. of coal. Allowance must be made for interest, depreciation, maintenance, etc., but, taking coal at 35s. per ton, and 3500 working hours per annum for the gas engine, the net saving would be about £450 a year on a capital outlay of £600 to £800. An appreciable additional saving can be effected by using the preheated water from the jacket of the gas engine cylinder as boiler feed.

Important advantages are claimed for the "Still" combined internal-combustion and steam engine of which preliminary details have just been published.* The principles involved may be considered as a logical extension of the method of utilising the waste heat from gas engines outlined above, and comparisons of prime and operating costs will no doubt lead to considerable controversy. It would seem, however, that for chemical works where gas engines are installed, the use of a waste-heat boiler is usually to be preferred.

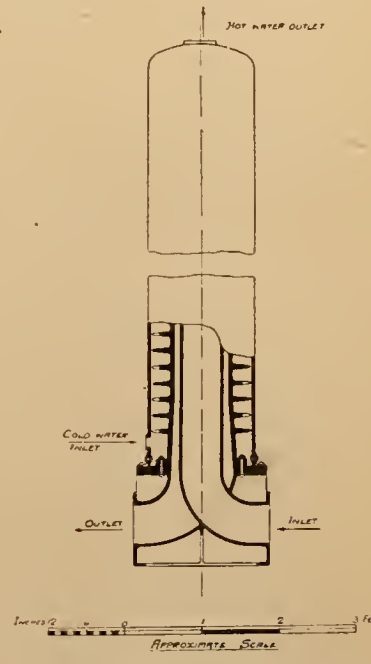
The amount of steam that can be generated in a waste-heat boiler does not vary greatly with the steam pressure required, and the difference between the temperature of the steam generated and that of the gases leaving the boiler varies between 30° and 80° C., according to the type of fire-tube boiler adopted.

It is not always appreciated that waste-heat boilers present a problem quite different from that of an ordinary boiler, and it is a common fallacy to suppose that the ordinary standard type of water-tube or fire-tube boiler will work really efficiently as a waste-heat boiler. Actually the surface exposed to the gases and the length and number of the tubes used require to be carefully calculated to suit each individual case in order that really good results may be obtained. In the author's opinion fire-tube boilers are usually preferable because it is impossible for air to leak into the waste gases and so cool them. Leakage of air through the brick setting and excessive radiation are, on the other hand, the great drawbacks of water-tube boilers used for the recovery of waste heat, especially when working with induced draught.

The following table in regard to a few sources of waste heat may be useful as indicating what may be possible in analogous cases:—

Plant	% of oxygen in products	Temperature of products of combustion	Percentage of net calorific value of fuel lost in products of combustion	Probable thermal efficiency of waste-heat boiler at 100 lb. pressure	Probable thermal efficiency at 20 lb. pressure	Minimum ultimate percentage of net calorific value of fuel lost at 100lb. pressure
Non-regenerative coke oven ..	10·0	1100°C.	81·0	70-80	72-83	10·9
Regenerative coke oven	10·0	600°C.	42·2	55-65	60-70	10·9
Regenerative open hearth furnace using producer gas	5·0	500°C.	33·0	48-60	55-67	10·5
Gas engine full load	9·0	480°C.	41·0	47-57	56-66	13·4
Regenerative gas works retorts using producer gas	11·7	410°C.	42·7	35-50	41-61	17·0.
Regenerative glass furnace using producer gas ..	2·9	410°C.	23·9	35-50	40-60	9·4

In chemical processes high steam pressure is the exception, and in many factories quantities of hot water are required or can be efficiently utilised. Waste-heat boilers are therefore particularly suitable for chemical factories. For gas engine in-



RUSTON TYPE WATER HEATER
FOR UTILIZING HEAT OF GAS ENGINE EXHAUST

FIG. 2.

stallations of less than 100 h.p. the amount of steam that can be generated is usually too small to be of any practical use, but in such cases considerable economies may be effected by installing

* Engineering, May 30, 1919, page 708.

water heaters instead of boilers. In conjunction with a gas engine between 10 and 18 gallons of water can be raised from 15° to 90° C. per B.H.P. hour in return for a very small capital outlay. Fig. 2 shows in part section a "Ruston" type water heater which is neat and simple in design; these heaters should be made of a special grade of cast iron or else "calorised" as described below.

In some chemical factories both high pressure and low pressure steam are often required, the former for power and the latter for evaporation and other processes. Proposals have been made to operate turbines or steam engines with high pressure steam discharging at about 60 lb. per sq. in. for use as low pressure steam throughout the works. The economics of this proposal, by which the turbine or steam engine practically acts as a reducing valve, are somewhat controversial. The use of waste-heat boilers will, however, often reduce the coal bill and save long lengths of steam pipe-work. Except for purposes of power generation and to keep steam dry, waste-heat boilers in chemical factories should not be provided with superheaters. For normal types of evaporators, heaters, and the like a slight degree of superheat is only required to compensate for condensation in a long steam pipe line, and it is a common fallacy to imagine that superheated steam is an advantage when used in evaporators. Superheated steam in such cases acts like a gas and the rate of heat transmission is less than when practically dry steam is used, in which case condensation of the steam plays an important part.

On the other hand, high temperatures are required for certain processes such as asphalt melting plant, oil stills, and various kinds of heat treatment. When high pressure steam as distinct from superheated steam is used, the apparatus must be strong enough to withstand the stresses due to the steam pressure, and this often makes design difficult or even impossible. In such cases the Merrill patent process of fluid heat transmission is often applicable and is mentioned here as it would sometimes come under the category of a utiliser of waste heat. In the Merrill process a highly refined and filtered hydrocarbon mineral oil (free from carbon and having a flash-point of 315° C. and upwards) is continuously circulated through the apparatus and through nests of heating tubes or absorber coils, which latter are either direct fired in a Dutch oven or may be adapted to utilise the waste heat from industrial furnace gases. The efficiency of heat transmission is high both on account of increased "thermic head" or difference of temperature, and because the heat transfer is from a liquid.

The waste gases from many processes contain appreciable amounts of dust or noxious gases. Dust is a frequent source of trouble in waste-heat boilers of the ordinary water-tube or fire-tube type, the dust settling on the water-tubes and brickwork containing them, or tending to choke up the fire-tubes. The obvious remedy is to increase the velocity of the gases sufficiently to prevent deposition of dust, but in the usual types of boilers this is only possible at the expense of efficiency. The Bonecourt Company have overcome the difficulty by using an inner metal tube, as shown in Fig. 3, the diameter of which is accurately calculated to give the desired velocity in any given case. The use of the inner tube also eliminates the relatively inactive central core of hot gas and enables fire-tubes of greater diameter to be used. Much will depend upon the nature of the dust in calculating the necessary velocity, which varies between that corresponding to a draught of between 1" and 4" of water. The author has also devised a method of breaking up this hot core of gas* consisting of spirals placed inside the tube at intervals of about six feet, the spiral being made with a pitch decreasing in the direction of the gas flow.

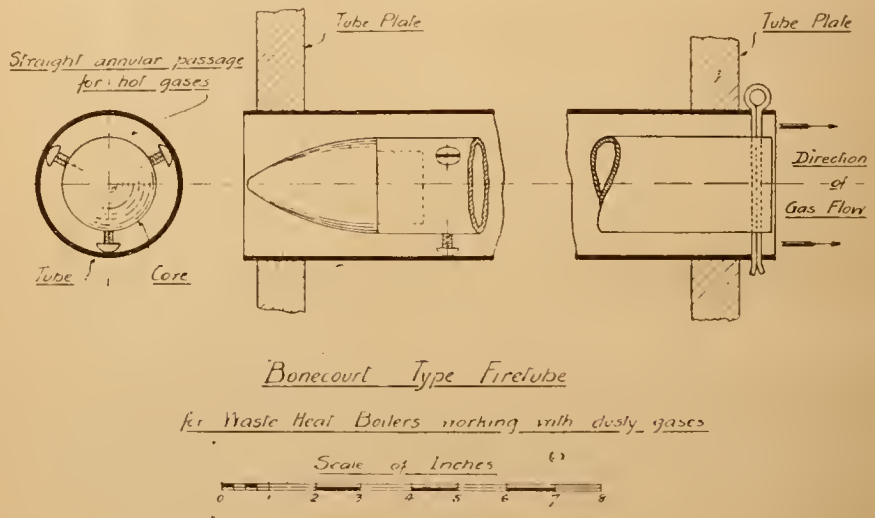


FIG. 3.

Tubular boilers have been successfully used in conjunction with arc processes for nitrogen fixation, the tubes being unaffected by the nitric oxide present at the temperatures used. For high temperatures, and in cases where sulphur dioxide is present at low temperatures, "calorising" or other protection for the tubes is necessary. "Calorised" tubes are now commercially available, the tubes, which may be of steel, copper, brass, or other metal, being heated in stationary or rotary retorts in a reducing atmosphere, with a mixture containing finely divided aluminium. This treatment conducted at a high temperature forms a homogeneous aluminium alloy for a certain depth in the tube varying from a few thousandths of an inch to the permeation of the entire mass. Calorised tubes are almost immune from burning, scaling, rusting, or corrosion, and are likely to find increasing application not only for waste-heat boilers and their

* Eng. Pat. 14,165 of 1915; J.S.C.I., 1916, 1145.

feed-water heaters but for pyrometer tubes, furnace castings, and chemical plant generally. Their use in feed-water heaters should in many cases eliminate the danger of corrosion referred to previously and should enable the heat contained in waste gases (particularly where sulphur dioxide is present) to be more completely utilised.

Part II. Pulverised fuel.

The modern tendency in regard to fuel economy aims at the prevention of the use of any coal in the raw state. Distillation of coal is, however, a long way from being universal, and is not usually applicable in the case of inferior or small graded fuel. The use of pulverised fuel in the raw state is essential only in isolated cases, such as the cement industry, and while its use will undoubtedly be greatly extended in the present transition period owing to the immediate saving in fuel that can be effected, its ultimate economic value and application lie rather in the possibilities of using inferior fuels, and of such coal and coal dust as have so far been considered commercially useless and have been dumped or left in the mine.

The combustion of pulverised fuel partakes perhaps more of the nature of chemical engineering than the subject of waste-heat boilers, and it is hoped that the following data and general considerations will be of guidance. The subject is such a large one that for the present purpose it was not desirable to do more than bring out salient points and useful facts and figures derived from so many sources that it would be impossible to make acknowledgment to all of them. A considerable amount of new matter has, however, been added together with expressions of opinion in regard to controversial points.

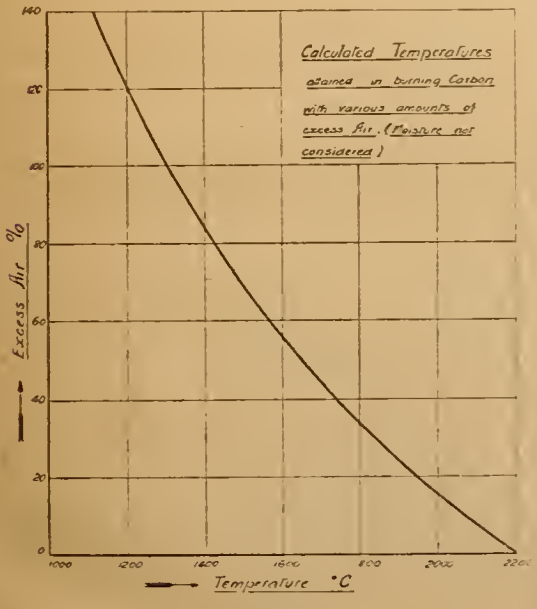


FIG. 4.

1. *Nature of fuel.*—Practically any quality of fuel—bituminous, anthracite, peat and lignite—can be burnt successfully. Choice of fuel is not entirely governed by its cost per unit of calorific value. The quality rather than the quantity of ash is of the greatest importance, also the sulphur content, which should not normally exceed 1%, though as much as 4% and more has been found permissible under boilers. Bituminous coal with 28% ash and averaging 6% sulphur has actually been burnt in locomotives. 30% volatile and 6 to 10% ash would be ideal.

2. *Excess air and temperature.*—Fig. 4 shows the effect of excess air on the calculated temperature attained in burning carbon, the figures being due to H. G. Barnhurst. In a hand-fired grate 100% to 200% or even more excess air is required and about 50% with mechanical stokers. With pulverised fuel about 20% is practically standard and considerably less can be used with careful control. The carbon dioxide content of the flue gases when using the theoretical amount of air is 20·7% and the loss in efficiency when this is reduced to 11% is only about 5%. Further reduction in the CO_2 content entails rapidly increasing loss in efficiency, the loss being as high as 25% of the total fuel burned when the CO_2 content falls to about 6% as in hand-firing practice. With powdered fuel 15% CO_2 represents good average practice. Similarly the higher flame temperature is obviously conducive to more rapid heat transference and therefore higher efficiency. With inferior fuels containing considerable percentages of ash the flame temperature and efficiency are materially reduced and, as previously stated, particular attention must be paid to the quality and properties of the ash and to its action on the brickwork. In fact, before using inferior powdered fuel very thorough investigation, particularly as regards prime and operating costs, is essential. In regard to the measurement of CO_2 content it should be noted that for controlling the combustion of pulverised fuel it is simpler to measure the volume of air used than to take the CO_2 content of the chimney gases, as the variation in the latter is much less in proportion.

Modern refractories are now able to cope with the high temperatures obtaining in the combustion chambers without artificial cooling devices such as embedded cooling coils or secondary air blasts. Zirconia bricks will probably be of great value. Correct proportioning of the combustion space is of vital importance, and about 1 cubic foot is usually required for every 3 lb. of coal burned per hour.

3. *Pulverising.*—95% through 100 mesh and 82 to 85% through 200 is now practically standard. The average fineness is 600 mesh or less, and the surface exposed to oxidation or combustion is about 26 square feet per pound; combustion is therefore almost instantaneous. Pulverised coal weighs between 38 and 45 lb. per cub. ft. and has an angle of repose of 15°—20°.

4. *Drying.*—The moisture content is usually reduced to at most 1% before use. It is quite possible to burn powdered fuel containing 4% of moisture, but it seems well established that, apart from inconveniences such as the possibility of freezing and agglomeration during storage, the loss of efficiency due to vaporising and superheating the extra moisture content in the furnace counterbalances the fuel required for drying. The overall cost of drying, however, is greater than the value of the heat lost in vaporising the moisture in the coal, and drying is mainly justified by the necessity of this operation for satisfactory pulverising, transportation, and storage in large plants. Actually if 2% of moisture is removed from the coal by drying, this is only equivalent to about 25% of that contained in the air used for combustion (based on the yearly average) and (allowing for the latent heat of vaporisation which has to be imparted to the moisture content of the coal) may be taken as roughly equivalent to that contained in the combustion air. It follows that for small self-contained pulveriser units, the cost of drying is not usually justified. This point is emphasised by tests recently carried out by E. R. Knowles on an "Aero" self-contained pulverising unit of 5000 lb. per hour capacity. It was found that coal containing 4% of moisture (of which ½% was combined moisture)

was delivered to the collector with only ½% of moisture or entirely free of surface moisture, the latter having been absorbed by the air during pulverisation. In another test wet coal containing 16·4% of moisture was delivered to the collector with only 4·4% of moisture. It should be noted that such results can only be obtained by air separation as moist coal would choke up any screening device.

5. *Ash.*—Of the ash content 65% can be collected as fused or semi-fused slag and may be run into a water-filled pit; "hard" and "soft" clinker are removed by blowing in steam occasionally or by mechanical means. The remainder of the ash probably goes up the chimney as a very fine white powder, which seems to cause no inconvenience in large towns.

6. *Costs and efficiencies.*—With power at say 0·7*d.* per kw. hour, pulverising varies from 1*s.* 6*d.* per ton for a 10-ton per hour plant to 2*s.* per ton for a 2-ton plant. Labour represents about 4*d.* in the former and 9*d.* in the latter case, two men being required for either.

A rotary dryer 6 ft. in diameter and 35 ft. long will dry about 10 tons per hour of coal of ¾" and under to about 0·5% moisture, using about 2% of fuel. If the furnace is close to the pulverising plant the waste gases can be used for drying the coal.

Inclusive of unloading, screening, removing "tramp iron," drying, grinding, and conveying to the furnace 2*s.* 6*d.* per ton would be an average figure (including wages) for preparing the fuel in a large plant. Against these costs economies in fuel of between 15% and 30% have been realised, the saving being even greater when a comparison is made between pulverised coal and producer gas in open hearth and other steel furnaces.

The cost of installation is about the same as for a producer gas plant of equal capacity, and according to a British quotation received in April, 1919, a plant to burn about 20,000 tons of pulverised coal per annum would cost about £14,500. The total operating cost including depreciation, interest on capital, insurance, taxes, wages, etc., would be about 3*s.* 6*d.* to 4*s.* per ton of fuel exclusive of the cost of the fuel. 15—25 kw. hours are required per ton.

General considerations.—Pulverised fuel is almost comparable in use and convenience to fuel oil or industrial gases, and combustion is smokeless and very complete. Temperature control and variation are easy, the desired temperature is very quickly attained, there are no stand-by losses, or loss of fuel as on a grate when a furnace is stopped, there is less ash left for disposal, and overloads up to about 200% can be quickly met. For chemical and metallurgical work it is possible to maintain either an oxidising, neutral, or reducing atmosphere. Screenings and coal dust can be used to advantage in the powdered form and no grading of coal is required. Apart from the possibility of using coal of inferior analysis, the author has suggested* that the semi-fuel resulting from low-temperature carbonisation, and particularly the dust inevitably resulting during transport owing to its rather friable nature, should be utilised in powdered form; it might also be possible to carry out low-temperature distillation of coal in pulverised form and then to burn the resulting semi-coke in pulverised form, the waste gases from the latter process being used to provide a neutral atmosphere for carrying away the products of distillation and to keep the powdered coal in suspension.

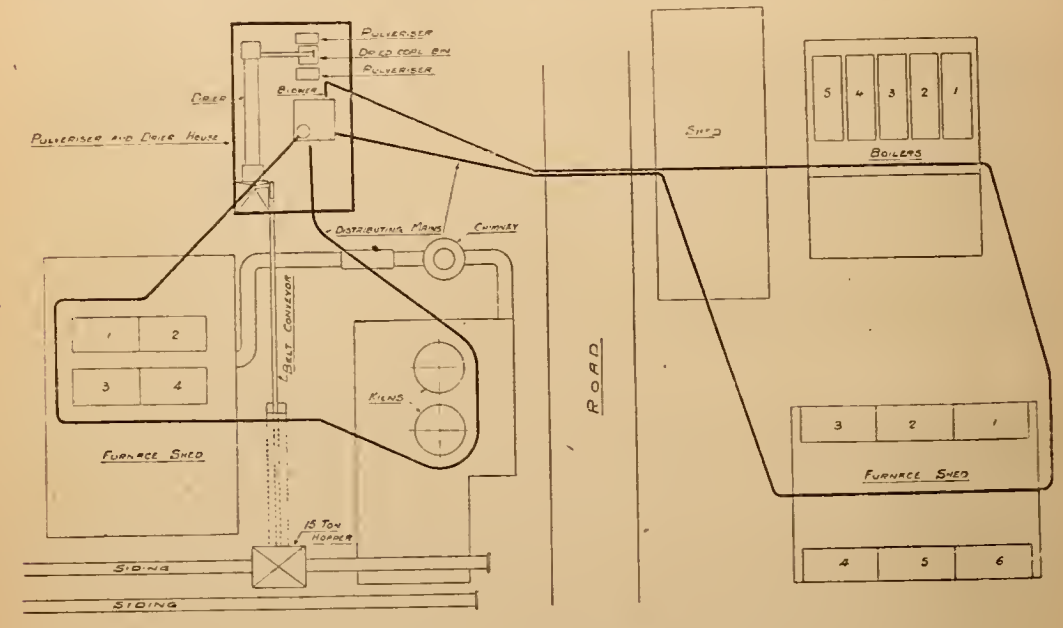


FIG. 5.

The three chief types of powdered fuel plant are:—

(*a*) Screw conveyor systems combined with storage bins and fans at each furnace unit.

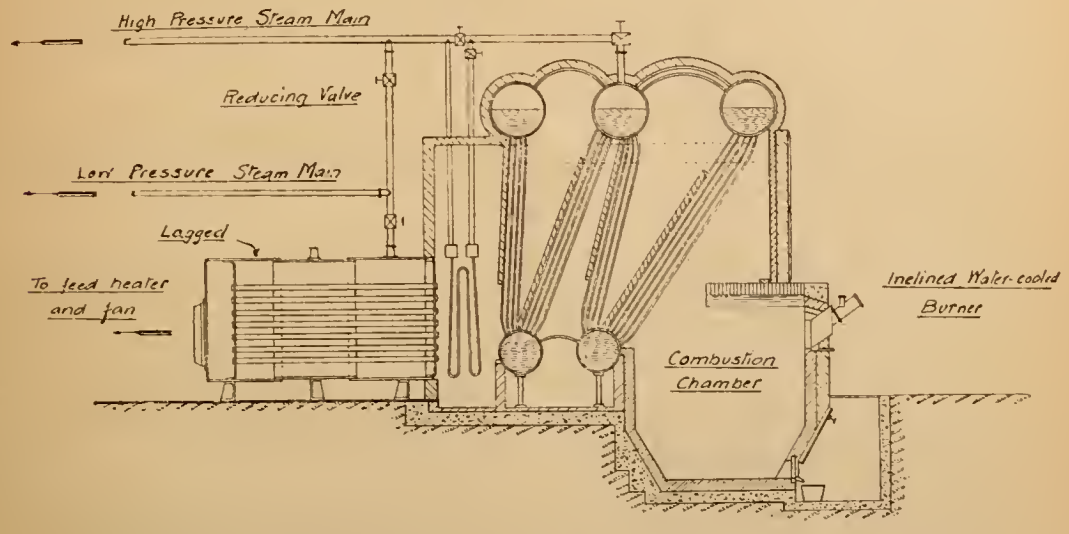
(*b*) Combined pulverisers and fans on the induced draught principle, one unit being provided for each furnace unit; (*a*) and (*b*) are particularly applicable in power plant, steelworks, etc., where the units to be heated are large and are conveniently placed in relation to each other, though very small units have also been successfully used.

* J.S.C.I., 1918, 219r.

(c) The "pneumatic" system, in which the pulverised fuel is carried in air suspension in a closed circuit and simply tapped off as and where required to units of any size. This system is probably that most suitable for chemical works, as it enables the pulverising plant to be concentrated and avoids the transport and storage of fuel throughout the plant. The maximum practicable distance of transmission from the central pulverising plant is about 750 feet, but by inserting a booster blower in the main or by providing sub-stations, the distance can be increased to cover a very large area.

The amount of "primary" air used for "carrying" the pulverised fuel is about one-half that required for combustion, the balance being admitted at the furnace unit from a secondary air main. It is important that the amount of primary air should be less than that giving an explosive mixture.

Fig. 5 shows a typical lay-out; the absence of the special fuel handling and distributing appliances and facilities which often take up much valuable floor space in a chemical works will be noted.



Combined Pulverised Fuel and Waste Heat Boiler Installation for Chemical Works

Scale of Feet

0 5 10 20

C J G.
1. 5. 19

FIG. 6.

Colloidal fuel.—When pulverised fuel is added to fuel oil together with about 1% of a "fixer," the latter causes the powdered fuel to remain in a state of suspension for a month or more. The resulting fuel can be burnt in exactly the same way and in the same burners as the original fuel oil. Various mixtures of this kind have already been successfully tried, using inferior materials such as coke, coal containing 25% ash, anthracite "culm" or washings, crude oil coke, coal tar, petroleum pitch, wax tailings, etc.*

The calorific value of one gallon of colloidal fuel is equal to or greater than that of the original oil, while at the same time the sulphur content is reduced.

Further research in colloidal fuel and in regard to the fixer presents a good field for the chemical engineer in connexion with the utilisation of waste products, and while during the war colloidal fuel has been mainly of interest for use in submarines and patrol vessels, the prospect of oil in Derbyshire may render its use profitable in industry, particularly if, as is probably the case, it can be used for raising steam in the very efficient "Bonecourt" gas-fired type of boiler, suitably modified. It is also within the bounds of possibility that powdered fuel can be burnt in such a boiler, using say a zirconia refractory filling. The difficulties in design are, however, very great.

Application in chemical works.—Apart from boiler plant, pulverised fuel should be applicable in many cases where industrial gases are now used, and in reverberatory and roasting furnaces of all kinds. The experience gained in cement works will find due application in other rotary kilns such as those treating greensand and felspar for potash recovery, alunite, bauxite, etc. Mechanical salt-cake furnaces, sodium sulphide furnaces, roasters, dryers, oil stills, oil cracking processes, and many other heat treatments readily suggest themselves, and in these days of accurate and scientific control the use of pulverised fuel presents undeniable advantages. Perhaps the greatest attraction is the possibility of materially reducing the number of operatives, two men being able to attend to several units, manual labour being practically eliminated, and supervision and cost-keeping simplified.

Coke is largely used in chemical works, and the mixing of coal of high volatile content with coke readily suggests itself. It is unversally stated that powdered coke has been tried and cannot be used as a fuel. This, in the author's opinion, is, however, too sweeping a statement, and further

* Submarine Defence Association, New York. See J.S.C.I., 1919, 165 R.

trials under correct temperature and other conditions should be well worth while.

In a Belgian factory, powdered coal was used for making sodium aluminate from a mixture of bauxite, sodium sulphate, and carbon, a neutral or slightly reducing atmosphere being necessary. The supply of coal having been cut off temporarily powdered coke was tried and found quite satisfactory provided that the combustion space was kept nearly white hot. For starting up, coal was essential, but this example seems to show that, using high-grade refractory linings, powdered coke may have possibilities in other processes.

General notes.—In connection with the use of waste-heat boilers in conjunction with furnaces, the point is often made that the boiler would be idle while the furnace is not in operation. This may be overcome, though with some loss in efficiency, by providing an auxiliary powdered fuel burner and if necessary a combustion chamber for the waste-heat boiler, the powdered fuel being turned on when the supply to the furnace is shut off, or when the rate of steaming requires to be increased.

In conclusion, a suggestion as to the possibility of the *combined* use of pulverised fuel and waste-heat boilers in chemical works may not be out of place. Fig. 6 shows in diagrammatic form a water-tube boiler fired with pulverised fuel directly connected to a waste-heat boiler and feed-water heater. By allowing the products of combustion to leave the water-tube boiler at a temperature about 200° or 300° C. higher than is usual, and then fully utilising the remaining available heat in a well-designed waste-heat boiler, a greater overall thermal efficiency, together with increased output and overload capacity at a lower cost per unit of steam generated, would be attained than in a single boiler unit of standard type fitted with, say, a Green's economiser. The calculations in support of this contention are, however, outside the scope of this paper.

The suggested combination is one peculiarly suitable for chemical works, as the water-tube boiler could supply high-pressure steam for power at say 300 lb. pressure, while the waste-heat boiler would furnish low-pressure steam for evaporation and processes. The high-pressure main would be connected to the low-pressure main through a reducing value and thus act as a stand-by. The waste-heat boiler in this case would be of the double tube type previously referred to in order to prevent deposition of dust from the powdered fuel.

This arrangement presents a further advantage in that very pure water is only required for the water-tube boiler, to which the condensed steam from turbines or the like is returned. The condensed steam from evaporation and process work cannot usually be returned to the boiler and the ordinary sources of water supply can therefore be used for the waste-heat boiler.

This combination is, of course, also possible with Lancashire and other types of boiler. Sudden demands for steam may be met by increased fuel supply and by reduced feed-water supply to the waste-heat boiler.

While it has been impossible to do more than touch upon the fringe of these subjects, it is hoped that this contribution will have demonstrated that waste-heat boilers, and particularly pulverised fuel, can, given suitable conditions, be successfully utilised in many chemical works and both in small and in large units. It is for the works manager and chemical engineer to take stock of their possibilities during the period of reconstruction and thus to co-operate in the national need of fuel economy.

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Discussion.

Captain Goodwin, in the course of some supplementary remarks, said he thought that the gas industry would probably do its full share as regards economy in the present altered circumstances, but would this be the case with the rest of the chemical industry? In the future chemical factories would be judged by what they did both in the national as well as in their own interest, and at the latest price for coal every source of waste heat might be worthy of serious examination. As an extreme case, even the water used for cooling powdered-fuel burners should be utilised. When waste-heat boilers had been first thought of, the chief principle in regard to their use had really been non-interference with the operation of the primary furnace, particularly as regards chimney draught. Experience had shown that induced draught not only paid, but was conducive to regularity and convenience in working.

The use of powdered fuel had long been considered a failure in this country, because except in cement works it was not properly understood and the principles of its application had not been thoroughly worked out by chemical engineers. As in America alone 11 million tons was burned annually, it was now evidently a serious factor, although in this country we should have to confine our attention chiefly to semi-fuels, to anthracite dust, inferior coals, and lignite. Maximum flame temperature was of great importance and was affected by moisture content as well as by ash and excess air. Thus in the "Aero" pulveriser, in which the coal was dried during the process of pulverisation, the whole of the moisture was not eliminated as in a dryer, but went forward with the fuel into the furnace, so that only the heat of vaporisation was saved at the expense of a reduction in flame temperature. He had referred to the "compound" boiler installation with some diffidence, but the analogy between this and the compound steam engine and its economy was evident and encouraged him to make the suggestion, whatever its result might be. As an alternative to the use of

an economiser and perhaps a waste-heat boiler, it was possible to pass furnace gases through a recuperator or brick regenerator in which the secondary air for powdered fuel burning was pre-heated before entering the furnace. Whilst the efficiency of the arrangement would be lower than that of a good waste-heat boiler, the scheme had some possibilities where low-pressure steam or additional steam was not required.

Dr. W. R. Ormandy, referring to the attitude which science was taking in the matter of fuel, said that in a recent speech Mr. Smillie had referred to the fact that we were using our fuel badly, and adopted that as an excuse for extorting special terms. Reference had also been made frequently to the possibilities of saving fuel if electricity were utilised on a large scale. The reports on this subject were merely preliminary and were open to much controversy, and it was important to exercise the greatest care in making any statements as to the economies which might be effected, because they might be used in the wrong way. It was true that a great deal of fuel had in the past been and was to-day being used uneconomically, but it was also true that a vast amount of this fuel had been wasted because there was as yet no prospect of being able to use it more economically. It was stated, for instance, that the efficiency of using fuel in a glass-melting furnace was something of the order of 2%, and that a very large proportion of the heat was radiated from the face of the brickwork of the furnace, but that if any attempts were made to stop that, the brickwork would fail in a short space of time, and although heat was wasted, there was no immediate prospect of saving it. Much had been said about the waste of fuel in steam raising. It had been his duty to examine the efficiency of many scores of large ranges of steam boilers for the Bradford Dyers and Fine Cotton Spinners for large industrial works in the North. In almost every case these large concerns had economisers and superheaters, but one source of economy that should be aimed at was keeping up the CO_2 percentage above 10%. The power required for the induced-draught fans for a range of boilers was very considerable, and it required very careful examination to find out at what point it was worth while putting in induced draught. If, on the other hand, induced draught enabled the use of a fuel so low in grade that it could not be used on the ordinary type of stoker, then there was much in its favour. Some collieries in the North were now using roofing shale containing 55% of combustible matter which it would be utterly impossible to use without induced-draught plant. So far the only application of powdered fuel in this country had been to cement-burning in rotary kilns. We required much more information with regard to the grade of fuel which could be used. For instance, if it were possible to use a powdered fuel which had previously been subjected to low-temperature distillation, it opened up great possibilities. Low-temperature distillation of a low-grade fuel was in many cases rendered uneconomical because, though the apparent value of the oil might be considerable, it was not sufficient to pay for the entire cost of the process, and some use must be found for the high ash residue; but if that residue were easily pulverisable and could be used in the form of powdered fuel, it opened up the possibility of a combined low-temperature process which would enable a large amount of fuel now wasted to be made use of; the smoke problem in that case would be a difficulty, however. The question of the utilisation of comparatively low-temperature gases seemed to him to be bound up very closely with finding some metal or alloy or some method of treating metals which would make them resistant to sulphur dioxide, because the lower the grade of the fuel the more certainty there was of producing large amounts of sulphur dioxide. The temperature of the exhaust of gas engines was also one that should be considered in that connection, because it seemed to him that for feed-water heating and industrial purposes there was an advantage in low-temperature heat. Finally, he asked the author whether he had any records as to the temperature that could be obtained in brick-kilns or pottery furnaces, such as those of the Hoffman type or even down-draught furnaces, using coal-dust fuel with cold air, and alternatively with hot air, assuming the fuel used to be of a good average calorific value.

Mr. L. C. Harvey said that the principal difficulties with regard to the use of powdered coal had been primarily the accumulation of ash and slag and the cutting away of the refractory brick-work. These were the two chief objections, especially in boiler work, but with modern types of pulverisers these two defects had been entirely overcome. Boilers now were being fired with pulverised coal very successfully indeed, straight line efficiencies of 75—85% being obtainable with fuels which had not been previously usable either with mechanical stokers or with gas producers. Sir Auckland Geddes had stated recently that a loss of 7*d.* per ton on coal delivered in London was due to the loss of smalls. The smaller the coal the better it was for pulverisation, and all that loss in coal delivered in London could be utilised in that form. A considerable quantity of dust and almost what might be called dirt was still left at the mines and was not a saleable fuel. In America during the last two months the lowest grade of fuel, anthracite slush or pit washings, containing less than 5% of volatile matter and 25—30% of ash, had been dried and pulverised and used at the Susquehanna collieries; the results with this fuel were so good, showing a boiler furnace efficiency of 80%, that the new boiler houses of about 4000 H.P. at their collieries at Lykens and Lytle, Pa., were now being fitted entirely with pulverised coal burners, and in this way they would only use pulverised slush which previously had been valueless. There was no doubt that we had used our fuels very wastefully indeed, but not more so than the Americans. In this country, in the puddling furnace industry, the fuel consumption was usually 3000 lb. of coal per ton of puddled iron, and nearly all the furnaces were hand-fired. In America, however, puddling furnaces had been converted for use with powdered coal, and the fuel consumption of 3000 lb. and sometimes 3500 lb. had been cut down to 1200—1600 lb. per ton of iron. At the same time five complete heats of puddled iron were obtained per shift instead of four, and without the production of any smoke whatever. The puddling furnace in this country had perhaps been our worst offender for smoke production. Under the old system of using powdered coal with high velocity gases, much of the fine dust which did not fuse in the combustion chamber was taken through the furnace or the boilers at high velocity and up the stack and deposited in the district. One of the secrets of success at the present time was the low velocity of the primary air and therefore low velocity of the gases through the boilers or furnaces, so that 60 or 70% of the ash should be deposited in solid or liquid form in the combustion chamber, 20 to 30% being deposited either in the furnace or on the boiler tubes in the form of very fine dust, ash, or slag, and not more than about 2%, consisting of the finest dust, would be emitted from the stack. There were in America numerous examples of successful installations for re-heating steel and for puddling iron, in which the capital outlay of the pulverised fuel plant had been paid out of profits during the first twelve months. Even so people over here were slow

to consider the question. In chemical works one of the deterrents to using pulverised fuel was the cost of the plant, but it was quite probable that very shortly small consumers would be able to purchase pulverised coal and only have to install in their works self-contained automatic feeder and burner units. These machines were working very satisfactorily in America, and they required very little manual attention, and for chemical processes the temperature could be regulated automatically by a thermostat control, so that once the canister of fuel was on the hopper the subsequent operation was automatic. In 1903, with coal at 7*s.* 6*d.* per ton, a pulverised coal installation burning 250 tons per day would have shown a net profit, after deducting all expenses, including interest and depreciation, of £1875 per annum. At the present time, with coal at 30*s.*, for the same size plant the saving would be £21,562.

Captain F. S. Sinnatt thought that powdered fuel had a very great future in regard to the utilisation of material in Lancashire that could not be used at the present time, and was being wasted day by day because it was not thought worth while to recover it. In one case the whole field was covered with a fairly good cannel with from 20 to 60% of ash. An attempt had been made during the war to use it for low temperature distillation, but it had not been the complete success anticipated; the fuel was very easy to grind. Soft coal was extremely difficult to grind.

Mr. H. M. Ridge said that the installation of waste-heat boilers was not a panacea for all evils for those who wanted steam or who had waste heat. He believed that the best economy of coal was obtained by restricting the heating use to the primary object which was desired. Take the case of the puddling furnace. If an excessive quantity of coal were burned in the puddling furnace an excessive quantity of waste gaseous products was produced, and then sent through a waste-heat boiler to recover the heat units. That, however, was not the primary purpose. The puddling furnace should be worked properly, and it should not be attempted to make steam in the same operation. If the waste gases were leaving the furnaces at anything like a high temperature the heat units in the waste gases should be recovered and sent back into the boiler by pre-heating the secondary air. In a recent case in which it had been desirable to reduce the consumption of coal as far as possible, the operation necessitated the waste gases leaving the furnace at a temperature at about 1300° or 1400° C., and they were being utilised for pre-heating the secondary air, thus reducing the temperature of the stack gases to about 250° C. That gave a financial result which it would have been very difficult to obtain if these very hot gases had been passed into waste-heat boilers. Whilst in the case he had referred to the quantity of gas was very great, he had done the same thing in a number of installations working on a comparatively small scale, using one or two tons of coal per 24 hours. It was possible, and in a number of cases in this country it had proved satisfactory, to pre-heat the secondary air and to obtain a good efficiency. In certain cases of which he had careful fuel records, the waste gas left the furnace, say, at 1000° C., and sometimes up to 1150° C., the secondary air being pre-heated to between 600° and 850° C.; the reduction in coal consumption had been more than 50%. That had been done in counter-current recuperators because with such a comparatively small coal consumption it did not pay to put in regenerative furnaces with reversing valves, etc. Whilst it was possible to save and use heat units that would otherwise be carried away in the waste gas, there were a very large number of cases in the country requiring further research work, such as the cases in which the gas was very dirty and carried a large amount of very finely-divided dust during the first portion of the temperature drop. Finally, he would like to refer to a remark made by Mr. Ingalls about three years ago in "The Engineering and Mining Journal" of New York. He had pointed out that it was not a desirable thing to burn an excessive quantity of coal or producer gas in a furnace in order to get a large quantity of steam, and he emphasised the desirability of restricting the furnace to its proper use and putting the boilers somewhere else. He quite agreed with that, but one disadvantage of waste-heat boilers was that after any stoppage, if waste gas only was being used for heating boilers, it was not possible to get steam at the beginning when it was most urgently required, and it was necessary to put in subsidiary power arrangements to overcome that difficulty.

Captain Goodwin, in reply, said he would answer some of the points raised in writing. In a large proportion of chemical factories the greater part of the steam was required for process work, and, in spite of what Mr. Ridge had said, it did sometimes pay to burn extra fuel at one end in order to get steam at the other. At the same time, he did not mean to indicate that a chemical factory should not look to the primary efficiency of its furnaces. With regard to induced draught, he reminded Dr. Ormandy that in a powdered coal furnace only about 1/10th inch water gauge was necessary, and with a properly designed waste-heat boiler the means to provide the draught needed did not require anything like the amount of power which Dr. Ormandy had suggested was necessary. He had referred in the paper to means by which corrosion from sulphur dioxide could be prevented, and he did not agree that an alloy would be found which could be used. He believed the solution would lie in coating, and "calorising" had already been successfully applied in soot blowers for boilers and the like. He agreed with nearly everything that Mr. Harvey had said. It was of very great importance that a curve of efficiency showing 75—85% could be obtained in a powdered coal installation at almost all loads between 25% and 200% or more of full load, whereas mechanical stokers lost in efficiency and reliability under overload conditions. He thought that smalls and particularly dust from the semi-fuels of low-temperature distillation should be collected by a central organisation in every large town and burnt in powdered form. He agreed that the velocity of the gases must be low in the boiler and in the combustion space, but it was quite permissible to use a higher velocity in the waste-heat boiler. Mr. Ridge had said that more heat ought to be extracted in the puddling furnace, but more heat could not be extracted there, because the temperature required was so high. He also did not think that 250° C. was a low enough temperature at which to send the gases up the stack; 160° C. would be more satisfactory.

In his written communication, the author pointed out that puddling furnaces and boiler plant *per se* did not really come within the scope of his paper. It was not now correct to say that cement works were the only ones using powdered fuel in this country. There could be no doubt that semi-fuel from low-temperature distillation could be successfully burnt in pulverised form, and he did not agree that there would be any difficulty in regard to smoke, as combustion would be practically perfect. "Blending" of fuels might be desirable in some cases. Temperatures sufficiently high for the heat treatment of steel were obtainable with powdered fuel, and there should therefore be no difficulty in meeting any reasonable requirements of brick and pottery furnaces; no data were yet available, and the conditions, particularly in pottery furnaces, were rather special.

Mr. Ridge did not state the thermal efficiency of the recuperators used; a good waste-heat boiler had an efficiency of over 80 % at the temperatures given, or nearly double that obtainable in regenerative working. A low stack temperature was of no value if the heat of the gases was not recovered efficiently.

Dr. M. O. Forster then took the chair.

DIFFERENTIAL PRESSURE METERS FOR MEASURING AIR, GAS AND STEAM FLOWS.

BY JOHN L. HODGSON.

(1) This paper contains a summary of the more interesting features of the metering problems mentioned in the title. A fuller treatment of many of the details will be found in the author's paper on "The Commercial Metering of Air, Gas and Steam" (Proc. Inst.C.E., 204, [ii.]).

(2) The differential pressure required to actuate the indicating or recording devices is obtained in the meters for which the author is responsible, either by means of a constriction placed in the pipe line, or by means of a special form of Pitot tube consisting of a cylindrical rod, at one end of which two pressure holes are bored, the one facing exactly upstream, and the other exactly downstream. These pressure holes are connected by means of suitable passages and pressure pipes to the indicator or recorder. The Pitot tube is inserted in the main so that the pressure holes are at the centre of the main.

The velocity in feet per second, V, of the central filament may be computed from the formula

$$h=\frac{WV^2}{158} \quad . \quad . \quad . \quad . \quad (1)$$

where h is the observed difference of pressure in inches of water, W is the density of the fluid in pounds per cubic foot, and 158 is a coefficient determined by experiment.

When applying this formula to the measurement of the volume passing, due allowance must be made for the distribution of velocity over the cross section and for the diminution in the area of the cross section caused by the insertion of the tube.

There are various forms of Pitot tubes on the market which purport to average the velocity over the cross section by using a number of holes instead of one central hole. Investigation, however, will show that the average velocity over the cross section cannot be obtained in this way if the distribution of velocity is irregular. The Pitot tube should therefore always be installed with good upstream conditions, or if these cannot be obtained, a traverse should be taken in two directions at right angles.

(3) From the point of view of the indicating or recording instrument, the Pitot tube has, in spite of its simplicity, two important defects. (*a*) On account of the low velocities commonly found in air and gas mains, the differential pressure produced is usually very small. (*b*) Owing to the fact that the maximum differential pressure produced depends on the maximum velocity in the pipe line, and that this varies in practice between very wide limits (*e.g.* 15 feet per second in a gas main to 300 feet per second in a main carrying superheated steam) the indicating and recording instruments would, if the Pitot tube were used as the basis of the measurements, have to be designed to deal with the numerous maximum "heads" from the most minute upwards, or else the diameter of the pipe line would have to be altered at the point where the Pitot tube was inserted in order to obtain a reasonable uniformity in the maximum heads dealt with.

Because of these defects, the author has developed only one instrument for use with the Pitot tube; the differential pressure in all other cases being obtained by means of constrictions placed in the pipe line which can be designed to give the differential pressure required by the instruments over a very large range of maximum velocities.

In addition to the above defects, the Pitot tube is much more dependent upon good upstream conditions than a constriction is.

(4) The instrument developed for use with the Pitot tube is termed the "curved tube" manometer (see fig. 1). It consists of a reservoir containing oil which is connected to the upstream pressure hole, and a curved tube connected to the downstream pressure hole, and so shaped that equal increments in the velocity past the Pitot tip will cause equal movements of the oil meniscus along its length. The manometer is so designed that it can be supplied to work at any maximum head between 15 and 120 mm. of oil. Owing to the equal-spacing scale, accurate readings can be taken down to 1/9th or 1/10th of the maximum flow.

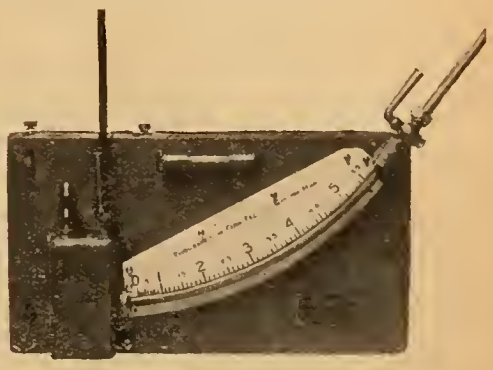


Fig. 1.

A larger type of the same instrument is now being developed in connection with high pressure gas distribution which will enable accurate readings to be taken down to 1/20th of the maximum flow.

The "curved tube" manometer can, of course, also be used in connection with the constrictions described later.

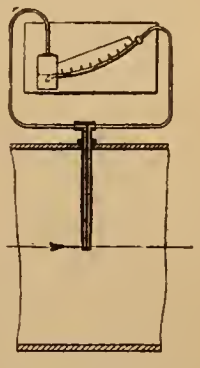


Fig. 2.

Fig. 2 is a diagram showing the "curved tube" manometer connected up to the Pitot tube.

(5) The best form of constriction to use depends upon many factors: the initial cost allowable; the differential pressure required; whether the fluid is of an erosive nature (*e.g.*, contains sand particles) or is liable to deposit mud or tar or naphthalene; whether the pipe line can be easily opened up to replace the constriction first inserted by one giving a greater or less throttling effect so as to bring the differential pressure produced within the best range of the indicating or recording instrument etc.

A more subtle consideration must also be taken into account if the coefficients of discharge of similar constrictions of various sizes are to be easily predicted from the calibration of one size alone, and the scales and cams and diagrams of the indicating and recording instruments are to be standardised; namely, the discharge must be exactly proportional to the square root of the differential pressure.

This last consideration, which is assumed as obvious in all elementary text-hooks, is actually one which it is very difficult to realise even approximately in practice. The position of the pressure holes, any abrupt change in the radius of curvature of the walls of the constriction between the upstream and downstream pressure holes, any undue roughness of the walls, too little guidance of the flow; all these affect the result.

(6) The well-known Venturi tube when properly designed is by far the most perfect of all the types of constriction. It consists of a gradually converging upstream section, a short parallel throat section, and a gradually diverging downstream section. This gradually diverging downstream section enables about 6/7ths of the differential pressure obtained at the throat to be recovered. The smooth curves of the upstream and throat sections ensure that the square root law is almost exactly obeyed, so that the flow through Venturi tubes of very large diameter can be accurately predicted.

From the point of view of gas measurement, the smooth curves of the Venturi tube have the extremely important effect of reducing the tendency for deposit to form to a minimum, a tendency which is on the other hand accentuated in those types of constriction which cause eddying.

The disadvantages of the Venturi tube:—(*a*) its relatively high first cost, (*b*) its great length, (*c*) the expense of replacing it when a higher or lower maximum flow than that for which it was designed has to be measured—have however necessitated the development of other and cheaper types of constriction.

(7) The simpler types of constriction have been mainly developed in connection with air and steam measurement.

The first of these simpler types of constriction used by the author consisted of a thin plate, in which a square-edged hole was bored, placed in the pipe line. The differential pressure was taken across two holes drilled in the pipe line on the upstream and downstream sides of the plate. Experiment soon showed that the same orifice would give different coefficients of discharge if the position of the pressure holes was altered, and that the same size of hole would give different coefficients of discharge if the thickness of the plate were varied, or the edge of the hole slightly rounded.

This led to the employment of a special fitting, the orifice carrier, for carrying the orifice plate, as the pressure holes could then be drilled in the plane of the upstream and downstream faces of the plate, and all sizes made geometrically similar. The employment of this special fitting carrying the orifice plate in which the pressure holes were drilled also enabled an orifice plate to be changed without having to consider how the position of the pressure holes affected the coefficient of discharge for particular diameter of orifice used.

It was found on further experiment that when the diameter of the orifice was more than about three-quarters that of the main, the coefficient of discharge became very dependent upon accurate centering and the smoothness of the pipe upstream of the orifice. This difficulty could have been partially overcome by fitting two or more sets of pressure holes, but as the minimum cost was the end in view, it was decided to concentrate the whole of the area of the obstruction around the pressure holes in the form of a segment of a circle bounded by a chord.

This was found very satisfactory until still higher velocities had to be measured, when it was found desirable to replace the straight chord by the arc of a circle of which the centre was at the pressure hole.

In order to reduce the errors due to inaccurate centering, the size of the hole in the orifice fitting at the orifice plate was made slightly smaller in diameter than that of the main, being coned down from a diameter slightly larger than that of the main.

In order to reduce the effects of chemical or mechanical erosion, the edges of the orifice plates were rounded, the effects of a given amount of erosion being found to be less on a rounded orifice than on one having originally square edges.

In this way the orifice carrier, the orifice plate, and the circular, segmental and tongue orifice plates were developed.

The various points referred to under this heading are illustrated in fig. 3.

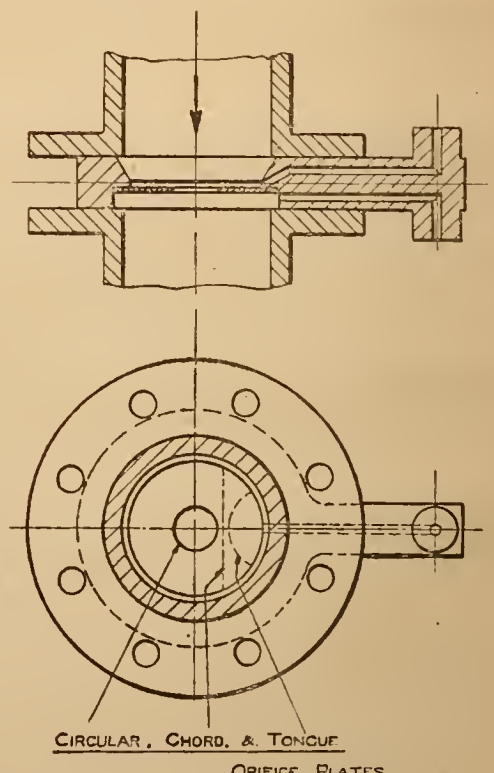


FIG. 3.

(8) It was found that the field of useful application of the air and steam meters especially would be greatly reduced if only high-priced meters were available. On the other hand, it was found impossible to design low-priced meters which would be reasonably accurate over a large range of flow. This will be easily understood when it is remembered that the differential pressure upon which the measurement depends is at one-fifth of the maximum flow only one-twenty-fifth part of that available at the minimum flow, and at one-tenth of the maximum flow only one-hundredth, and so on.

It was therefore decided to concentrate on the production of indicators and recorders which were accurate down to one-fifth of the maximum flow,

as it was felt that such meters would cover the most usual requirements.

There were, however, a large number of cases where accurate measurement over a large range was essential. To meet these, a further type of constriction was developed. This consisted of a butterfly valve which could be clamped in four definite positions, the coefficient of discharge for each successive position being approximately double that for the preceding one. With this construction, the range over which accurate measurement was possible with the indicators and recorders already developed was increased from 1 to 5 to 1 to 40.

The position of the butterfly valve has, of course, to be adjusted by hand when a new maximum flow is decided upon. But it is not necessary to shut down the flow or open up the pipe line, and this in itself is a great convenience.

(9) The law of flow past a constriction may be expressed by the formula:—

$$Q=\sigma.\phi.A\,[(p_1-p_2)W_1]^{\frac{1}{2}} \quad . \quad . \quad . \quad (2)$$

where Q is the discharge in pounds per second, and σ is the "discharge intensity coefficient" for the particular type of obstruction—a coefficient here used for the first time, which includes the discharge coefficient, Ω, and the ratio of the area of the main to the area left by the obstruction n; its actual value being $\Omega/\sqrt{n^2-1}$.

ϕ is a term which allows for the compressibility of the fluid. Its values for various values of n and p_2/p_1 are given in fig. 4.

of orifice Ω increases as the ratio p_2/p_1 diminishes according to the empirical relation

$$\Omega=0{\cdot}914-0{\cdot}306\ p_2/p_1 \quad . \quad . \quad . \quad (4)$$

owing to a progressive increase in the diameter of the vena contracta with increase of velocity.

In the case of "stream line" nozzles, this change in the value of Ω with velocity is almost inappreciable.

(10) In certain cases, as when supplying steam to water-gas generators, the usual practice of generating the steam at some 60 to 90 lb. pressure and injecting it into the generator at only a small pressure above that of the atmosphere permits a large drop of pressure across the constriction.

Theory shows that if the ratio p_2/p_1 is less than a certain critical value, which depends upon the ratio of the specific heats of the fluid, and the ratio of the area of vena contracta at the constriction to that of the main,* equation (2) no longer holds, the discharge then being given by an equation of the form,

$$Q=\sigma.A(p_1+\alpha) \quad . \quad . \quad . \quad . \quad (2a)$$

where α is a numerical constant, and p_1 is the absolute pressure in the upstream side of the constriction.

In such cases a simple pressure gauge may therefore be graduated to show the rate of discharge of the steam at a given wetness or superheat, provided that a form of obstruction is chosen for which σ does not vary with p_2/p_1.

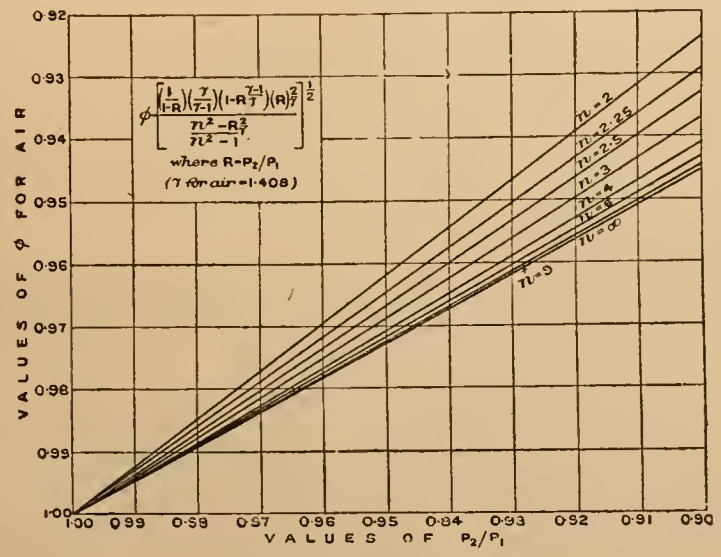


FIG. 4.

A is the area of the pipe at the upstream pressure hole in square feet; p_1 and p_2 are the pressures at the upstream and downstream pressure holes respectively in pounds per square inch. W_1 is the density of the fluid. Its values for various values of n and pressure hole. For pure dry air $W_1=2{\cdot}6998\ p_1/T_1$, where T_1 is the absolute temperature in ° F.

For a square-edged orifice having a diameter less than three-quarters of that of the main, and pressure holes in the plane of the orifice, and for which p_2/p_1 is not less than 0·99, $\Omega=0{\cdot}608$ and $\phi=1$ (nearly) so that (2) reduces to

$$Q=0.668\ \frac{A}{\sqrt{n^2-1}}\left[(p_1-p_2)\frac{p_1}{T_1}\right]^{\frac{1}{2}}\text{ lb. per sec.} \quad . \quad (3)$$

The reason why it is necessary to specify that p_2/p_1 must not be less than 0·99 is that for this type

Experiments carried out by the author at Messrs. Parsons' works at Newcastle in 1912 and at the Taylor air-compressing plant on the Montreal River, Ontario, in 1913, showed that while σ varied very considerably with p_2/p_1 for a square-edged orifice as indicated in equation (4), a shaped nozzle could be devised for which σ was practically constant for all values of p_2/p_1.

It may be of interest to note in passing that in both the above sets of experiments nozzles of over 1000 H.P. capacity were used.

The method of regulating the steam supplied to water-gas generators by means of a pressure gauge connected to the pipe on the upstream side of

* See equation (23) Appendix I. of paper before the Inst. Civ Eng. above referred to.

the obstruction was, as far as the author is aware, first employed by Mr. H. E. Bloor at Birkenhead some 1¼ years ago. Mr. Bloor, however, used it as a means of regulation only, and not as a means of measurement; as the discharge coefficients of various types of nozzles and the fact that they varied with the flow had not then been determined.

D is the diameter of the main and μ is the coefficient of viscosity of the fluid.

"High velocities" may be defined in this connection as those at which the effect of elasticity masks the effect of viscosity.

A fuller treatment of the matters dealt with in paragraphs (9) to (11) will be found in the paper

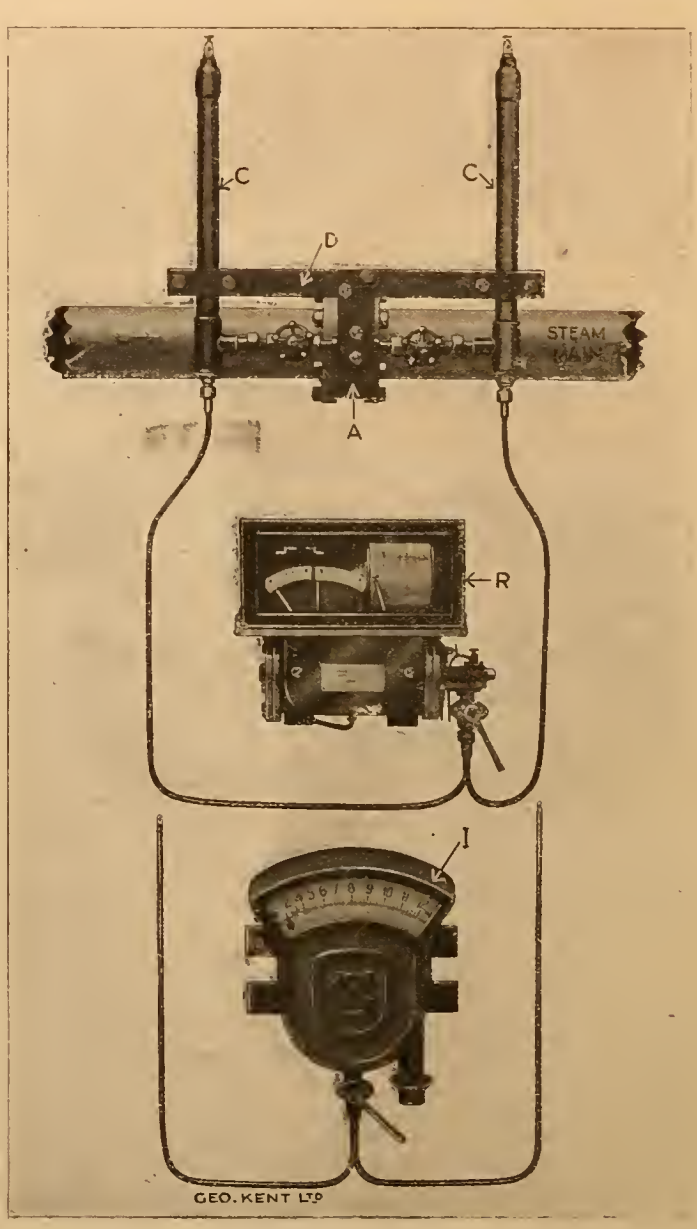


Fig. 5.

(11) When comparing the discharge of geometrically similar orifices of different sizes the "discharge intensity coefficient," σ, and the coefficient of discharge, Ω, are the same for high velocities for the same values at the ratio of p_2/p_1, and for low velocities for the same values of $\frac{V.D.W\dagger}{\mu}$ where

† For this relation to be strictly true, the geometrical similarity must extend to the relative roughnesses of the surfaces of the constrictions compared.

before the Institution of Civil Engineers above referred to.

(12) Certain precautions must be taken when installing the pressure pipes to ensure that the differential pressure produced is truly transmitted to the indicator or recorder. In the case of air and gas meters, moisture or other condensable matters are liable to deposit. To prevent errors due to this cause, the pressure pipes must be of a sufficiently large diameter and must be laid at a sufficient slope

to drain, sumps or drainage siphons being provided at the lowest points.

The case of the steam meters is more complicated. Here the indicators and recorders have to be full of water, it being impossible to keep these full of live steam, even if this were desirable. The line of demarcation between the water in the pressure pipes and the steam in the main must, however, always be at the level of the pressure holes, as otherwise the true difference of pressure across the orifice will not be transmitted to the instrument. The desired result is obtained if the pressure holes are brought out horizontally at the same level, and the pressure pipes laid horizontally for a sufficient distance before they bend upwards or downwards to the recorder. This method was patented by the author in 1909. As, however, it gave rise to considerable difficulties during installation another method was developed. This consisted of replacing the two lengths of horizontal pressure pipe by two vertical water chambers, the major part of whose

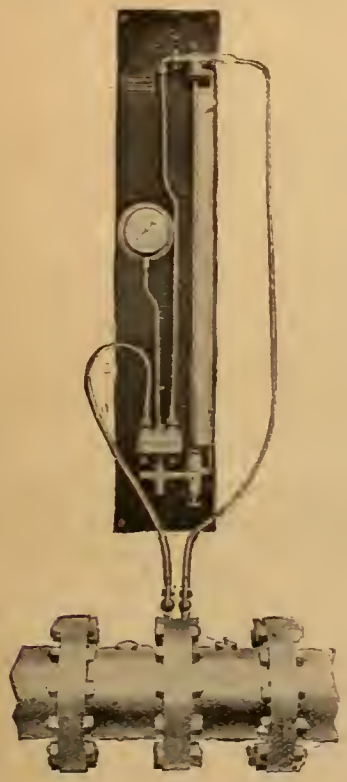


FIG. 6.

capacity is *above* the level of the pressure holes. Pressure pipes are taken to the recorder from the lower ends of these water chambers. Obviously, as long as the water level in these chambers remains above the level of the pressure holes in the orifice carrier, the true difference of pressure is transmitted. This simpler and more compact arrangement is the one now used by the author. A further precaution to be observed in the installation of the steam meter pressure pipes is that they must be of such a size and must be laid at such a slope that they can be readily freed from any air which may separate out from the water, or which may be trapped when connecting up, air vents being provided at the highest points. These water chambers and two forms of steam metering instrument are shown in fig. 5.

(13) Coming now to the indicating and recording instruments. The simplest types are, of course, those which merely indicate or record in terms of the differential pressure alone, the numerical value of the flow being obtained by means of suitable scales or charts.

The most convenient form of manometer consists of a reservoir and a gauge tube, the change of level in one limb only having to be read. This is termed the "single tube" manometer, and is illustrated in fig. 6.

The power required to record the differential pressure may be obtained from a float placed in a U-tube, or from an inverted bell sealed by fluid, or from a spring-controlled diaphragm, etc.

Where the static pressure of the fluid is high the differential pressure producing device must be entirely enclosed and its motion transmitted to the pointer or pen or cam through a gland. As it is impossible to devise a packed gland which will remain sound indefinitely, the gland is placed in such a position that slight leakage from it will not damage the instrument. The author uses magnetic glands on those instruments where very little torque has to be transmitted to operate the indicating or recording mechanism.

(14) Instruments which indicate or record in terms of the differential pressure only do not measure the flow with sufficient accuracy in those cases where the density of the fluid metered varies to any considerable extent.

Changes in the density of the fluid may be due to changes in its pressure and temperature, or to changes in its actual composition. The latter condition usually occurs only in the case of gas flows.

It is found in the case of air and steam flows that the temperature or superheat or wetness are usually fairly constant, and that the change of density can be taken as approximately proportional to the pressure alone.

(15) It will be seen on reference to equation (2) that if p_1 is assumed to be proportional to W, the flow becomes proportional to the square root of the product $(p_1 - p_2) \times p_1$.

In a so-called "pressure corrected" meter it is therefore only necessary to obtain and record the value of this product instead of $(p_1 - p_2)$.

Reference to fig. 7 will show how this is done in the case of the pressure-corrected steam meter.

The curved arm, S, is rotated through an angle proportional to the differential pressure by means of diaphragms contained in the body of the meter, B, while the end of the connecting rod, C, is moved vertically downwards through a distance proportional to the absolute pressure of the steam by means of diaphragms, P, subjected to the pressure in the main and working through the link, L.

The product of these two motions is transmitted to the pen arm, A, and recorded on a diagram, from which an amount proportional to the quantity passing can thus be read off.

(16) An entirely different method has to be adopted in the case of gaseous flows, where specific gravity of the gas relative to air at the same pressure and temperature may be continually varying.

Fig. 8 shows the scheme of a counter meter which takes into account variations in the specific gravity of the gas. In this meter the differential pressure is measured by a water-sealed bell, B, whose motion is transmitted by suitable means to a cam, E. This cam is so shaped that the feeler, H, which comes into contact with it adds on to the counter-reading an amount proportional to the square root of the differential pressure at each revolution of the heart-shaped cam, G, which raises and lowers it. The correction for variations in the specific gravity of

the gas is obtained by making the speed of rotation of the heart-shaped cam inversely proportional to the square root of the specific gravity by driving it from a small wet gas meter which is rotated continuously by gas escaping from the main through a small orifice, O, to atmosphere; the pressure across this orifice being maintained constant by a sensitive regulating-valve. In this way the counter is made to register the actual volume passing.

Meters of this type, in spite of their apparent complexity, have been found to be extremely reliable in practice and are of course enormously cheaper than the costly station meters they are designed to replace. Their readings are accurate down to 1/10th of the maximum flow, which is usually sufficient for station gas meters. They are superior to the simpler and cheaper rotary meters in that they have no moving parts in the pipe line and are not liable to derangement by tar, etc.

(17) The Venturi tube, which is used with these meters, is of course liable to become clogged by naphthalene, tar, etc. In order to reduce such clogging to a minimum the tube is installed vertically in a by-pass with the gas entering from above so that any liquid carried by the gas will drop right through the tube; the throat and the upstream sections are steam heated, a precaution which practically eliminates deposit; the throat can be cleansed by water jets without opening up the main, and, lastly, the throat section is made easily removable for inspection and cleaning when the tube is by-passed.

(18) The above paragraphs deal briefly with the theory and construction of the simpler differential pressure meters for which the author is responsible.

Their accuracy under working conditions is within 2% at full load and within 4% at the lowest loads they are designed to measure. When used for the measurement of pulsating flows their accuracy is, however, less.

The investigation summarised in Table IIA. of the author's paper before the Institution of Civil Engineers shows that with viscous damping in the pressure pipes the "pulsation constant" to be applied to the meter is practically independent of the wave form of the pulsation, and does not deviate from unity by more than about 7% provided that the variation of the rates of flow at the extreme phases of the pulsation does not exceed 1:2. In most cases where the measurement of pulsating flows is possible, the additional error caused after allowance has been made is less than ±2%.

(19) The various differential pressure producing devices made by the author's firm are calibrated with water, this method being simpler, cheaper, and, unless very elaborate care is taken, more accurate than calibration by air or steam or gaseous flows. Check tests are, however, taken on actual air, steam, or gas flows with each new type of con-

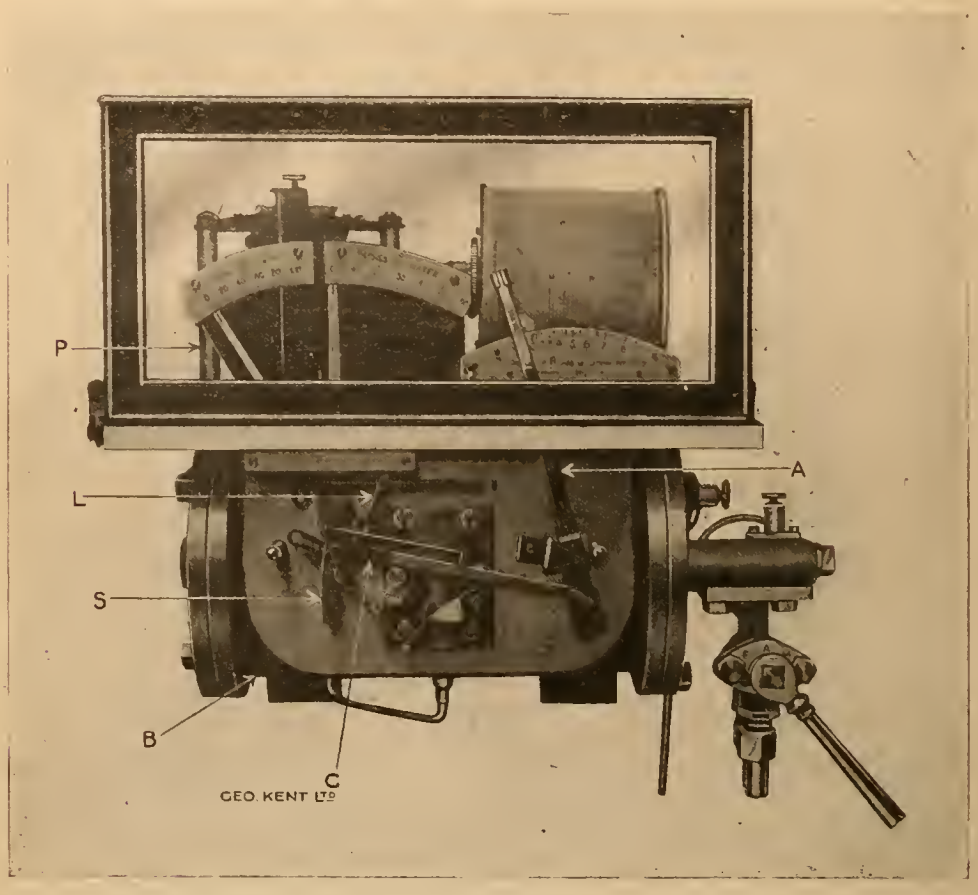


FIG. 7.

striction. The method of calibrating by means of water flows, which the author developed in 1909, enables a new type of constriction to be quickly tested out, and also enables the effect of difficult upstream conditions to be allowed for by means of scale models.

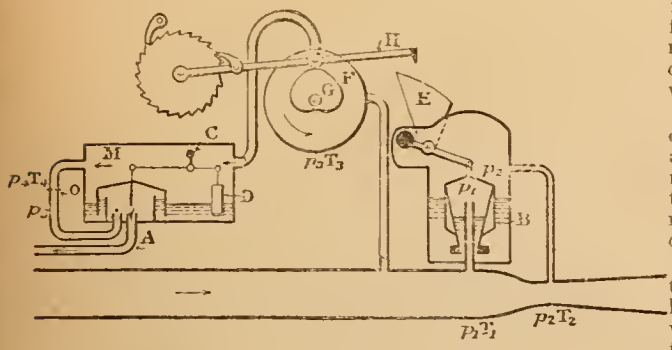


FIG. 8.

(20) All the types of meter dealt with can be arranged to register by counter. The integrating mechanism, which is the result of many years of experience and research, is entirely positive in its action. It consists of a powerful and beautifully made clock train which at two-minute intervals rotates a shaft which is thrown into gear with the counter at a fixed point in the revolution, and out of gear at a variable point, this variable point being made to depend upon the flow passing.

(21) In concluding this brief summary, the author would like to refer to the extreme importance of the right selection of materials for the various parts of the meters.

Thus, while a cast-iron orifice carrier and a gun-metal orifice plate may be used when measuring wet steam at low pressure or compressed air, these materials must be replaced by cast steel and nickel when superheated steam is measured.

Or, again, a meter which is perfectly satisfactory for measuring coal gas has to be completely revised if it is to be applied to the measurement of coke-oven gas, carbon dioxide, chlorine, or ammonia. With each new application new materials have to be chosen and tested.

(22) The author desires to thank the Institution of Civil Engineers for the loan of the blocks for figs. 4 and 8, and his firm, Messrs. Geo. Kent, of London and Luton, for the loan of the blocks for figs. 5 and 7.

RECENT DEVELOPMENTS IN SURFACE COMBUSTION BOILERS.

BY PROFESSOR WILLIAM A. BONE, D.SC., F.R.S., AND P. ST. G. KIRKE, M.A., A.M.INST.C.E.

Introduction.

What is now known as the Bonecourt system of surface combustion embodies the practical results of certain discoveries made by one of us during scientific researches upon the influence of hot surfaces in promoting gaseous combustion. It is recognised nowadays by all chemists that chemical interactions in gaseous systems are promoted by the catalytic action of hot surfaces, and the case of gaseous combustion is no exception to this general law. The researches referred to proved that if an explosive gaseous mixture be either injected on to or forced through the interstices of a porous refractory incandescent solid, under certain conditions, a greatly accelerated combustion takes place within the interstices or pores; or, in other words, within the boundary layers between the gaseous and solid phases wherever these may be in contact and that the heat developed by this intensified combustion would maintain the surface in a state of incandescence without any development of flame, thus realising the conception of flameless incandescent surface combustion, as a means of greatly increasing the general efficiency of heating operations wherever it can be conveniently applied.

Perhaps the simplest illustration of this system of flameless incandescent surface combustion is afforded by the diaphragm method of applying radiant heat, and it was obvious from the first that important results would accrue if by any means it could be successfully applied to the raising of steam in gas-fired boilers.

It will probably be generally admitted that up to a few years ago the gas firing of steam boilers had not been very successful from the point of view either of thermal efficiency or rate of evaporation. The low thermal efficiency of boilers fired in the ordinary way by blast furnace gas is notorious, whilst even in the case of boilers fired with coke-oven gas the thermal efficiency probably did not much exceed 65% or 70%.

The first experiments made in the year 1909 by the late Mr. C. D. McCourt and one of us upon the application of the principle of surface combustion to the gas firing of multi-tubular boilers, proved the possibility of transmitting between 90% and 95% of the net calorific value of coke-oven gas to the water in the boiler. The nature of these early experiments has already been dealt with so often in

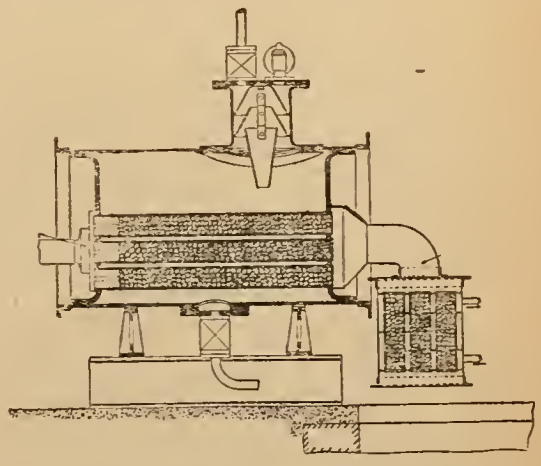


FIG. 1.

public that it will be unnecessary for us to enlarge very much upon them. Suffice it to say that the first experiment in Leeds was made with a single steel tube 3 ft. in length and 3 in. in diameter, packed with fragments of granular refractory material, meshed to a proper size, and fitted at one end with a fireclay plug through which was bored a circular hole ¾ in. diameter, for the admission of the explosive mixture of gas and air at a speed greater than that of back-firing.

Experimenting with such a tube, it was found possible to burn completely a mixture of 100 cub. ft. of coal gas plus 550 cub. ft. of air per hour, and to evaporate about 100 lb. of water from and at 100° C. (212° F.) per hour (20—22 lb. per sq. ft. of heating surface), the products leaving the further end of the tube at practically 200° C. This meant

the transmission to the water of 88 % of the net heat developed by the combustion, and an evaporation per sq. ft. of heating surface nearly twice that of an express locomotive boiler. The combustion of the gas was completed within 4 or 5 in. of the point where it entered the tube. Of the total evaporation, no less than 70 % occurred over the first linear foot of the tube, 22 % over the second foot, and only 8 % over the last foot. This pointed to a very effective "radiation" transmission from the incandescent granular material in the first third of the tube, where the zone of active combustion was located, although it should be remarked that the loci of actual contact between the incandescent material and the walls of the tube were so rapidly cooled by the transmission of heat to the water on the other side that they never attained a temperature even approaching red heat. The granular material in the remaining two-thirds of the tube served to baffle the hot products of combustion and to make them repeatedly impinge with high velocity against the walls of the tube, thus materially accelerating their cooling, and either preventing or minimising the formation of the feebly-conducting stationary film of relatively cold gases which in ordinary practice clings to the tube walls, seriously impairing the heat transmission.

From this initial experiment Bone and McCourt proceeded to construct their first experimental boiler (Figs. 1 and 2) which was made of ten such tubes fixed horizontally in a cylindrical steel shell capable of withstanding a pressure of over 200 lb. to the sq. in. This small boiler was connected with a small tubular feed water heater containing 9 tubes, each 1 ft. long and 3 in. diameter, similarly packed with granular material to facilitate the exchange of heat.

With this simple combination of boiler and feed water heater we were able to transmit to the water 93·3 % of the net heat units contained in London coal gas of 510 B.Th.U. net per cub. ft. at N.T.P. and obtain an average rate of evaporation of as much as 33·9 lb. water per sq. ft. of heating surface per hour (from and at 212° F.); the steam gauge pressure was 103 lb. and the products of combustion left the feed water heater at a temperature of 289° F.

The details of these results are shown in Table 1.

Table 1.

	8 Dec. 1910.		8 Jan. 1913.
Net cal. value gas in B.Th.U. per cub. ft. at N.T.P.	562	..	510
Rate of evaporation lb. water per sq. ft. heating surface per hour from and at 212° F.	21·6	..	33·9
Pressure of gaseous mixture entering the tubes. Ins. W.G.	17·3	..	40·9
Pressure of products entering the feed water heater. Ins. W.G.	2·0	..	5·14
Steam gauge pressure in lb. above atmospheric	100	..	103
Boiling point water in Fahr.°	338°	..	340°
Temperature products leaving boiler in Fahr.°	446°	..	534°
Temperature products leaving feed water heater Fahr°.	203°	..	289°
Net heat supplied to boiler per hour in B.Th.U.	559,800	..	728,333
Net heat transmitted per hour in B.Th.U.	527,800	..	680,000
Efficiency ratio	0·943	..	0·938

Skinningrove Boiler for Coke-oven Gas.

The success of this first experimental boiler enabled us to proceed immediately with the erection of a much larger plant (Fig. 3) on similar lines for coke-oven gas, at the Skinningrove Iron Works in the year 1911. It consisted of a boiler drum 10 ft. in diameter and 4 ft. from front to back, traversed by 110 steel tubes each of 3 in. internal diameter, packed with fragments of suitable refractory granular material. To the front of the boiler was attached a specially designed gas feeding chamber which delivered washed coke-oven gas at the ordinary temperature and under a pressure of 1 to 2 in. water gauge to each of the 110 combustion tubes. This gas, together with a regulated proportion of air from the outside atmosphere, was drawn under suction from a fan, through a short mixing tube, into each of the said combustion tubes where it was burnt without flame in contact with

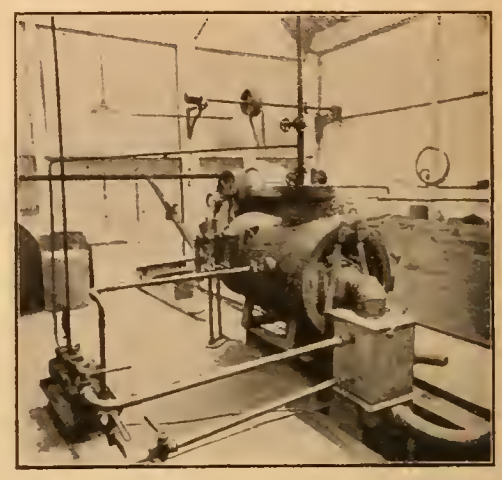


Fig. 2.

the incandescent granular material. After leaving the boiler tubes the products of combustion passed onwards into a semi-circular chamber at the back of the boiler, into a tubular feed water heater and from thence they were drawn by the fan which discharged them at a temperature of 95° C. into the atmosphere.

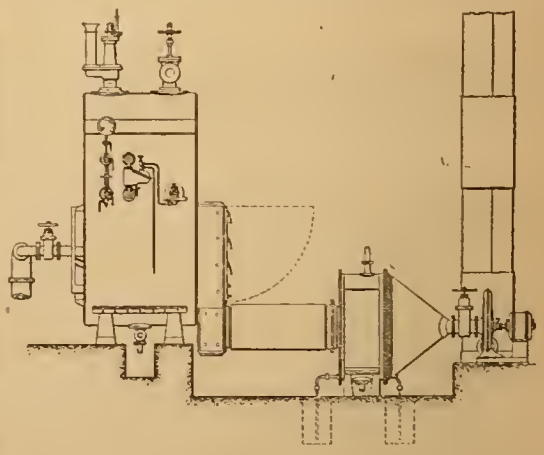


Fig. 3.

In a series of independent trials carried out on the plant by an eminent American steam engineer in July, 1912, it was found that, even when the boiler was not lagged and when it was raising steam at a pressure of 100 lb. above that of the atmosphere, 92·7 % of the net heating value of the coke-oven gas was transferred to the water and sent out as steam, the overall evaporation being at the rate of 14 lb. per sq. ft. of heating surface per hour (see Table 2).

As is often the case, the first attempt to translate a new idea of this kind into everyday large-scale practice was not unattended with difficulties, the investigation of which has taught us certain valuable lessons. There was no difficulty whatever with the Skinningrove boiler or boiler tubes, or

with the gas feeding arrangements. Notwithstanding the high evaporation, the mechanical properties of the tubes were not in the least impaired, and the Skinningrove experiences have shown that there is nothing wrong with the evaporating part of the installation. On the other hand, the type of fan put down at first to draw the gases through the system and to discharge the cool products of combustion into the atmosphere was found to be unsuitable for dealing with corrosive gases containing small quantities of oxides of sulphur at the extremely low temperature of 95° C., to which the products were reduced by the feed water heater. The burnt products had no corrosive action at all upon the boiler tubes or tube plates, but they were found to attack the outlet tube plate of the feed water heaters and the fan impellers.

TABLE 2.

Results of Steam Trial.

July 29th, 1912.

Duration of test in hours	10
Mean steam gas pressure in lb. per sq. in. above atmospheric	97·2
Total gas burnt in cubic ft. at N.T.P.	101,853
Net calorific value of gas B.Th.U. per cub. ft. at N.T.P.	510·5
Total *net* heat supplied. B.Th.U.	52,003,996
Temperature of products leaving boiler in Fahr.°	386(196° C.)
Temperature of products leaving feed water heater in Fahr.°	202(94·6° C.)
Total water evaporated in lb. from and at 212° F.	49,824
Evaporation in lb. per sq. ft. of heating surface per hour	14·1
% of dryness of steam	99·3
Total heat utilised in B.Th.U.	48,208,399
Ratio $\frac{\text{heat utilised}}{\text{net heat supplied}}$	= 0·927
Power taken by fan [suction = 20" W.G.]	= 6097 watts = (say) 8·2 h.p.

The average temperature of the products leaving the boiler when evaporating at a gauge pressure of 95 lb. to the sq. in. was about 195° C., or only 28° C. above the temperature of the steam. The effect of the feed water heater first installed was to reduce this temperature to practically 95° C., which was too low to prevent corrosive action. According to our experience, 120° C. is the lowest limit to which the temperature can be reduced without the risk of corrosive action upon the fan, and to allow a sufficient margin of safety at light loads it would be preferable not to reduce it below 130° C.

As there was no superheater, the work which could be done by the feed water heaters in reducing the products from 195° C. to 130° C. was so small that it was decided, in altering the Skinningrove plant, to cut out the feed water heater altogether and to substitute fans running at a lower speed and fitted with water-cooled oil ring lubricated bearings on account of the higher temperature of the products to be dealt with, and this has been done. The efficiency of the plant, now that the boilers are lagged, will still be about 90% on the net calorific value of the gas supplied, even without the feed water heater.

Boilers with Rigid Block Packing for Producer Gas.

Several other boilers of the Skinningrove type, with certain modifications in the packing and burners, and reduced suction, have been installed by the Bonecourt Waste Heat Boiler Co., Ltd., London, on the mains of the South Metropolitan Gas Company and the Gas Light and Coke Company. From a technical point of view we are still prepared to erect large boilers of the modified Skinningrove design for coke-oven or coal gas, and to guarantee their high thermal efficiency and smooth working, but as the result of more recent developments in regard to the structural features of the boiler, we would now recommend one or other of the types to be described presently, which have been duly protected by patent applications.

Although a boiler with 100 or more tubes, each 4 ft. long by 3 in. diameter, packed with loose fragments of a suitable granular refractory material, as in the case of the Skinningrove boiler, is eminently suitable for use with a perfectly dustless and tarless gas, such as coke-oven gas, it is preferable, when dealing with gases which are liable to contain dust or tar, to substitute a special rigid system of refractory surfaces (Fig. 4) over which the combustible mixture sweeps and in contact with which it is burnt at a highly accelerated rate. This has enabled tubes of much greater length to be used, which has the advantage of reducing the diameter of the boiler, reducing the number of burners, and reducing the cost of construction for a given evaporation. A further advantage is that the amount of suction required has also been considerably reduced.

FIG. 4.

The use of this new rigid system of refractory packing has also reduced the maximum temperature produced on the packing surfaces in the front part of the boiler to a degree certainly below 1000° C., and probably to about 850° C. This has been done by facilitating the heat transmission to the water by free radiation from the whole of the packing surfaces to the tube walls. As an illustration of these newer types of boilers we may describe the constructional features of two boilers erected in the year 1914 in the Birmingham district for generating steam from gas made in Kerperley producers (Fig. 5).

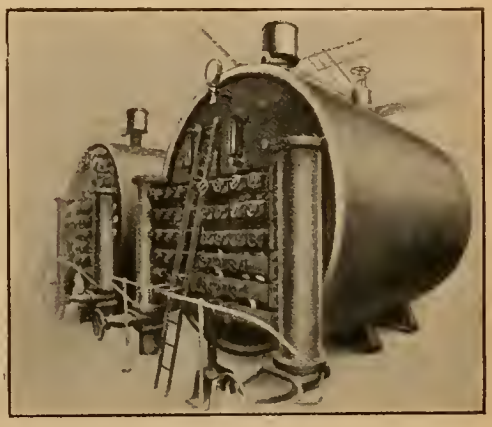


FIG. 5.

These boilers are each 10 ft. diameter by 12 ft. long; each unit contains 38 tubes, 6 in. diameter, packed with the special rigid system of moulded refractory blocks. Each of the tubes is provided with its own gas supply, which can be easily regulated by means of a wheel-valve on the boiler front, whilst the air requisite for combustion, together with a regulated proportion of gas, is drawn into each tube, through a short mixing chamber, by the suction of an electrically driven fan situated at the

back of the installation. Each unit will evaporate up to 15,000 lb. of water from and at 100° C. per hour. The combustion in the tubes is perfect, and when operating at a gauge pressure of 85 lb. per sq. in. the products leave the system (there being no feed water heater included in the installation) at less than 250° C.

These two boilers, it may be said, have been running continuously for nearly five years, and no tubes have yet had to be renewed in them.

The only criticism which we have to pass as the result of experience gained in working them, and which led us to adopt further modifications, is that we did not consider that a burner system which involved the use of separate wheel-valves for each tube of the boiler could be regarded as finality, and that it would be an advantage, from the point of view of evaporative power, if by any means tubes of smaller diameter and still greater length could be adopted in order to increase the heating surface.

The next step was an important improvement in the design of the burner, which has enabled us to dispense entirely with separate control for each boiler tube and to feed a whole nest of tubes from a gas-box controlled by one valve. The elements of this design are shown in Fig. 6. The illustration

Fig. 6.

of this newest burner shows a gas chamber controlled by one valve capable of supplying gas to a nest of 26 boiler tubes. The gas is fed into the chamber from a main on which there is a cock controlling the pressure in the gas-box. The front of the box is bored with a number of holes, of the correct size, each of which is immediately opposite the axis of one of the boiler tubes. These holes are of uniform bore, but their diameters are adjusted by a rimer in such a way that with a given gas pressure in the box each delivers exactly the correct quantity of gas to each boiler tube even when that quantity may vary slightly in different tubes. Hence the quantity of gas admitted to each tube depends simply upon the pressure in the box, which is controlled by the single valve referred to. While the quantity of gas is controlled by the gas pressure, the air is controlled by the fan, and all the operator has to know is how to vary the two together for different loads, which information is given him by the company's expert when the boiler is first put into commission.

Boilers with Spiral Packing.

The next illustration (Fig. 7) shows a small boiler operating on London coal gas with natural draught fitted with such a feeding chamber. The boiler contains 26 tubes, each 2 in. in diameter and 4 ft. long. Each tube is fitted with an iron packing of spiral form (Fig. 8), the front part of which becomes red-hot and acts as the catalysing surface for the combustible mixture, and so completes the combustion flamelessly in the first foot of the boiler tube. The products of combustion sweep through the system in a spiral motion and rapidly give up their sensible heat to the water.

Experiments upon Superheat.

During the early stages of the development of our designs we were concerned mainly with the problem of evaporation and heat transmission. The important subsidiary problem of superheat was left until later. It was of course recognised that it would be impossible to develop the system for large power station work where high superheats are required unless a satisfactory solution of the subsidiary problem had been arrived at. During the war the problem was tackled at the Bonecourt

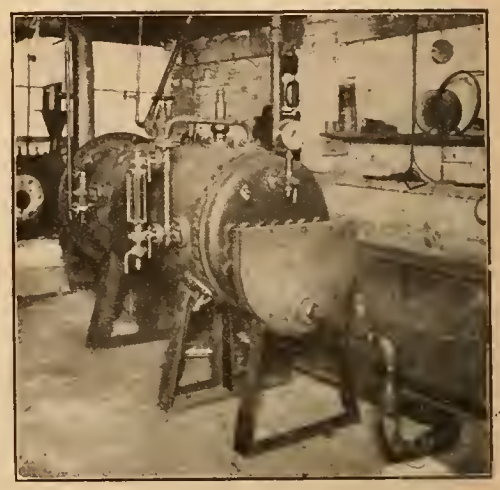


Fig. 7.

Waste Heat Boiler Company's works on an experimental scale, with results which have enabled the boiler design to be modified so as to provide for superheats up to the highest degree required in modern power station practice. As these experiments were begun at a time when we were using tubes of 6 in. diameter, the well-known and well-tried locomotive type of superheater adapted for insertion in flue tubes of 5½ in. diameter or thereabouts was first tried.

Fig. 8.

In the first experimental arrangement a tube 13 ft. long and 6 in. diameter was packed for the first 4 ft. of its length with the aforesaid rigid block packing, for the next 6 ft. with a superheater element, and for the remaining 3 ft. with a specially shaped packing. The tube was fitted into a boiler shell 18 in. diameter suitable for a working pressure of 100 lb. to the sq. in. The gaseous mixture was burnt and the temperature of the products reduced to 1300° F. (about 700° C.) before reaching the superheater element, and, after leaving the latter, the sensible heat remaining in the products was rapidly given up to the water in the boiler. By means of this arrangement steam at 100 lb. pressure was superheated 192° F. to a total temperature of 530° F., while at the same time the temperature of the products leaving the system was reduced to 442° F., which was only 104° F. (58° C.) above the temperature of the saturated steam in the boiler.

No feed water heater was attached in this experiment. In another experiment a superheat of 340° F. was obtained; the total temperature being 678° F., but in this case the temperature of the products leaving the system rose to 500° F., or 162° F., (90° C.) above that of the saturated steam in the boiler.

The improvements already described in the burners of the boilers, and the return to tubes of smaller diameter made it advisable to discard the locomotive type of superheater in favour of a modified type of that commonly used in Lancashire boilers.

Finally a complete unit, as shown in Fig. 9, comprising the boiler, burners, superheater, feed water heater and fan, all on one foundation, has been designed. The boiler itself is 6 ft. diameter by 18 ft. long. There are two nests of tubes which are packed with the iron spiral packing already referred to. Each nest is fired from one burner-box and controlled by one valve. The packing of the tubes is so arranged that the products of combustion will pass from the boiler to the superheater at a temperature of 500° C., more or less according to the amount of superheat required, while the sensible heat contained in the gases leaving the superheater

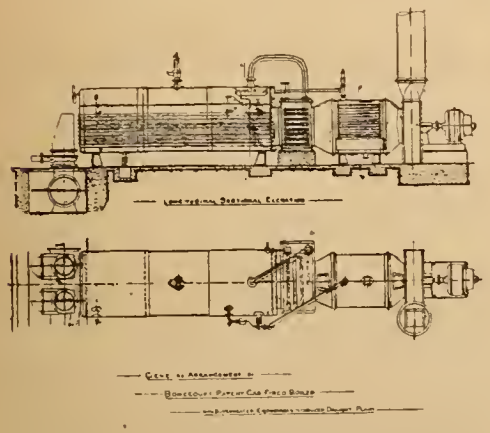


Fig. 9.

is recovered in the feed water heater, the temperature of the gases being reduced to 130° C. in the feed water heater, at which temperature they enter the fan. Such a combined arrangement of boiler, superheater, and feed water heater in one unit has the advantage that it allows of a greatly increased evaporation in the boiler itself per unit of heating surface as compared with the former arrangement of boiler only, and, so far as can be estimated from our experiments, this small boiler would easily evaporate 20,000 lb. water from and at 212° F. per hour when supplied with coke oven gas, and 15,000 lb. from and at 212° F. per hour when supplied with producer gas. In either case the suction would not be more than 9 in. of water, and the overall thermal efficiency would be the same as in the original Skinningrove unit.

As the pressure at which steam is generated in modern central power stations is rapidly increasing it is interesting to note that the boiler shown in Fig. 9 can be made out of ordinary plate for a working pressure of 450 lb. to the sq. in.

Objections sometimes put forward against shell boilers are not applicable to the Bonecourt boiler as, like the shells used in water-tube boilers, they are neither subjected to contact with the hot gases, nor used as part of the heating surface. Moreover, unlike some water-tube boilers, the shell plates are not drilled to accommodate tubes. They have the great advantage over water-tube boilers in that there is no internal pressure tending to burst the tubes. The tubes are floated by the water, and as the water can flow to the heating surface over the whole length of the tubes instead of only at one end, the boilers can be forced in an extraordinary manner without risk of priming or of burning the tubes out.

In water-tube boilers it is common practice to couple a number of shells in parallel. In the Bonecourt boiler, not only can drums be placed side by side, but also one above the other and yet controlled by a single set of steam fittings. One of the last forms of the boilers recently installed for coke-oven

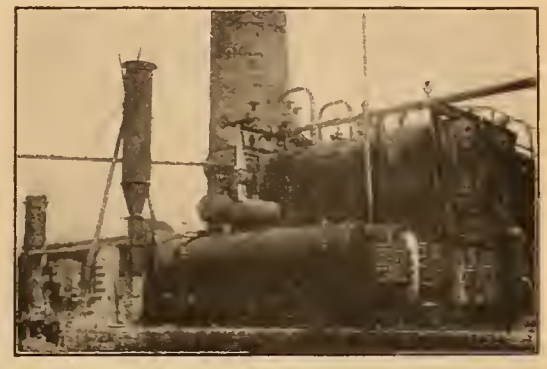


Fig. 10.

gas at a colliery in Cumberland is shown in Fig. 10. From these remarks it will be seen how easy it is to make a Bonecourt multi-drum boiler for almost any output and for any desired pressure and superheat, the space occupied being far less than that of any other boiler. Back-firing is impossible, and there are no large combustion chambers in which dangerous explosions can occur.

Waste Heat Boiler Development.

In addition to the development of surface combustion boilers described in this paper, considerable progress has been made commercially with the installation of waste-heat boilers in various parts of the kingdom, for the generation of steam from the hot products of combustion discharged from internal combustion engines and industrial furnaces.

Dr. Charles Carpenter presided at the afternoon session, when Prof. Bone's paper was discussed.

Discussion.

Mr. H. J. Ping said that three years ago his firm had put down a Bonecourt boiler; the immediate advantages of it were that they had not to arrange for coal carting nor for the disposal of ash, whilst a big chimney stack was not required. The whole thing was self-contained, and all capital expenditure on the items he had mentioned was cut out. In addition there were no stand-by losses worthy of mention such as there would be with a large range of steam boilers, Lancashire, water tube, or Cornish, and as the boiler was lagged the total losses were slight. The furnace which he had installed had five burners and five 6-inch tubes, with solid fireclay packing of the spiral type. There were two or three periods during the day when the load was zero and two or three periods when it was a maximum. The working of the boiler was very simple, the attendant being supplied with instructions based on their knowledge of the working conditions in the factory, showing the number of burners he was to work at each half-hourly period.

Dr. W. R. Ormandy asked what was the limit of poorness of the gas which it was possible to employ in this boiler and if it had answered to use pre-heated air when using gas of a very low calorific value, say 100 B.Th.U. He also asked whether in works where producers were installed, having regard to the losses necessarily entailed in running producers, the overall efficiency plus the producer loss would show any advantage over a direct-fired boiler which was run economically, unless the producer was able to use a low-grade fuel which could not be employed upon modern mechanical stokers. It was that aspect of affairs which would largely determine whether it would pay to install this type of boiler. Some 15 years ago Mr. Lester, of Manchester, had made a small model boiler consisting of a copper tube of about ½ in. diameter and 3 ft. long surrounded with a copper tube 1½ in. diameter. Cold water was fed through the annular space from the bottom and steam taken off at the top, and a mixture of coal gas and air was blown into the top of the smaller inner tube under sufficient pressure to form a long fine jet, the velocity being such that back-firing could not take place. With that an efficiency of 99·2% of the total heat value was obtained and, indeed, the apparatus could be used as a means of measuring the thermal efficiency of the gas comparable in accuracy with the ordinary Boys calorimeter. That scheme did not, however, appear to be capable of being worked out on a large scale.

Prof. Bone said that Dr. Ormandy had asked whether gases of low calorific value could be used. He had already explained that they were working with ammonia recovery producer gas of about 140 B.Th.U., but he presumed Dr. Ormandy referred to low grade blast-furnace gas. Very soon after the earliest experiments had been made he had had the opportunity of testing the experimental boiler tubes on blast-furnace gas at the Skinningrove works, and had found that the surfaces could not be got to glow sufficiently, by feeding in blast-furnace gas and air in proper proportions, to induce a very satisfactory surface combustion. The boiler tube was then started with a little coke-oven gas from the batteries near by, and as soon as the material was in a sufficient state of glow the mixture of blast-furnace gas and air was turned on and the boiler worked satisfactorily. About five minutes was sufficient for that purpose. Once the surface at the front end of the tube was in a satisfactory state of incandescence the process would go on. The question of putting down a boiler for blast-furnace gas in preference to a generating plant had been mentioned. In that case the blast-furnace gas would have to be so clean that greater efficiency would be obtained by putting it into an internal combustion engine than in any boiler system or even a steam turbine. There were circumstances in which the employment of an internal combustion engine with blast-furnace gas was not desirable, in which case there would be no difficulty, if the gas was cleaned—by an electrostatic method preferably—in dealing with it on the same lines as they did with producer gas. With regard to Mr. Lester's experiments, he believed that the amount of gas fed into the tubes was only a few cubic feet an hour, and if he himself were to feed the same quantity of gas through his own tubes at that rate he would be able to get the same efficiency of over 99%.

Mr. Kirke said that just before the war started he had gone over to Cockerill's works in Belgium and made experiments with blast-furnace gas on 6-in. tubes 12 ft. long, but he had had some difficulty with it. An evaporation of 20 lb. per square foot of heating surface was obtained with blast-furnace gas, but it was very difficult to burn. He had to start by getting the gas into the tubes at a very slow rate, and when it became properly mixed—he was not working with an explosive mixture—he could speed up very much; provided the combustion were completed before the water-cooled tube was reached everything went well. Cockerill's had been so satisfied with the demonstration on a single-tube boiler that they had determined to put up a big blast furnace gas-fired boiler and turbine and run it side by side with their big blast-furnace gas engines to see which was the best proposition. Just as they had started, however, the war had broken out. He believed, however, that there would be no difficulty in using blast-furnace gas, but it would not be possible to use a very long boiler unless the air were pre-heated. Pre-heating of the air would undoubtedly make it so much easier to burn blast-furnace gas, and for this purpose he would use an air heater of the underfeed stoker make at the exhaust end in order to enable the boiler to be made as long as possible. With regard to the question of the overall efficiency, the boiler efficiency was a little over 90% with a feed water heater, but the producer efficiency was not more than 75 or 80%, so that the combined result was not better than that obtained with a direct fired coal boiler, and the proposition only became interesting if the by-products could be recovered. That necessitated a large scheme, and it would probably only pay to put in a producer with a boiler in a large power scheme where the by-products were recovered. The next point raised was about the explosive mixture and back-firing. When they had first started these boilers they had worked with an explosive mixture, and had attempted to pass it through the hole at such a high speed that it could not fire back, but sometimes it would do so. They had then tried to dispense with explosive mixtures and to make it impossible for the charge to back-fire. The air was drawn in by the fan, and the mixing of the air and gas took place in the tubes while combustion was going on. The first part of the combustion took place by flame, and it was accelerated by the refractory material in the tubes. How much took place by flame and how much by surface combustion he did not know, but it did not matter because the combustion of the gas was complete with approximately the theoretical quantity of air. They had also done a good deal of work in connection with the recovery of waste heat, most of it with gas-engine exhausts, because the gas engine had plenty of power to drive the gases through the tube. The chief advantage of the Bonecourt waste-heat boiler over the ordinary waste-heat boiler was that large and thick tubes could be used which could easily be cleaned on the water side. The amount of water in the boiler, also, was considerably reduced, so that steam was got up much more quickly and condensation of the products in the tubes only took place while the water was getting hot; it was condensation in the tubes while the boiler was getting hot that caused corrosion of the ordinary waste-heat boiler tube, so that the objection to the ordinary waste-heat boiler was completely eliminated by the Bonecourt boiler. The boiler could also be made so short that it could be got into quite a small space and turned vertically upwards without the efficiency being in any way impaired.

The Chairman said he thought the authors had proved that a steam boiler could be made an economical appliance, and that if it were desired to convert hot water into steam it could be done by the means which had been described, always provided that the gas was obtained under economical conditions. One speaker had said that one of the advantages of the Bonecourt system was that the boiler could be switched on and off very much like a motor, and it had then been pointed out that that was all very well as long as there was an independent supply of gas; but if the supply of gas had to be incorporated with the steam-raising plant,

then they were face to face with stand-by losses. He thought that the stand-by losses of a producer would not be anything like those in the case of an internal or Babcock fired boiler. In other words there was a much greater control over the production of gas in a producer than by handling the dampers in any of the ordinary forms of boiler.

THE PRODUCTION OF STEAM FROM LOW-GRADE FUEL AND A CHEMICAL WORKS POWER PLANT.

BY P. PARRISH, A.I.C.

The application of a hard and fast rule is impossible when determining the best type of prime mover for a chemical works. Much depends upon the nature of the operations, what these involve in the shape of power and heat, whether the disposition of the chemical plant admits of the power plant being centralised, or whether such plant necessitates the installation of a number of small power units at various points throughout the works.

The major portion of the prime mover at the works under review is required in connexion with plant for:—

(1) Disengaging ammonia from ammoniacal liquor, which is treated in continuous columnar stills; the gaseous ammonia being absorbed in such a way as to produce liquor ammonia, ammonium sulphate, sulphite, chloride, and polysulphide.

(2) Promoting the formation of sulphuric acid in the chamber process.

Approximately 1000 tons of gas liquor is treated per day, and about 75 tons of chamber acid is made per day. Other chemical processes are conducted, but those named are the most important. The several processes involve a variety of chemical and mechanical operations, which may be briefly cited as follows:—Distillation (under pressure and under vacuum), condensation, calcination, concentration, dissolution, crystallisation, lixiviation in vacuum filters, filter-pressing, centrifuging, drying, grinding, disintegrating, screening, elevating, and conveying, etc. Despite these several operations, the power load is relatively small compared with the total prime mover required, and constitutes only 18—20% of the aggregate load.

As steam is the best medium for disengaging ammonia from ammoniacal solutions, not only from the point of view of its heat value, but also as regards its carrying effect, it would appear that the choice of a prime mover is for the most part confined to steam.

The chemical works in question are immediately adjacent to the gas works, where large quantities of coal are carbonised, and as the resultant coke has to be graded and screened, there is a quantity of coke breeze immediately at hand.

At one time the disposal of this material presented difficulty, but the progressively increasing price of fuel of late years has compelled attention to its disposal.

The production of steam from low-grade fuel is a matter of fundamental importance. Certainly the problem is not a new one, but it can hardly be said that finality in the matter of efficiency has been reached. Coke breeze is a very indefinite term and may mean almost anything. Some gas engineers describe it as all the material passing through a $\frac{3}{4}$-inch screen. Others would regard such material, or at least that passing a $\frac{1}{4}$-inch screen, as coke dust. Whatever the correct definition of coke breeze may have been, it is certain that any such definition will need to be materially modified to cover the coke breeze supplied during the last two or three years of the European war. Owing to the absence of pickers at the coal belts, the ash content of the coal increased appreciably, and obviously this had its reflex action on the character of the breeze resulting.

The subjoined table shows the weekly tests of the breeze supplied during the last three months:—

Date	Ash	Moisture
1919	%	%
Jan. 10	20·1	13·6
,, 17	17·7	12·8
,, 24	17·0	16·0
,, 31	27·7	13·8
Feb. 7	21·8	13·7
,, 14	17·1	12·7
,, 21	22·4	14·8
,, 28	21·3	13·1
Mar. 7	23·5	15·5
,, 14	20·2	15·7
,, 21	17·9	13·6
,, 28	24·6	16·0

Average screening tests of such fuel are:—

Percentage passing 1″ screen	25·74
,, ,, ½″ ,, ...	43·05
,, ,, ⅜″ ,, ...	71·66
,, ,, ⅛″ ,, ...	83·72
Remaining	16·28

It is recorded that more than thirty years ago Messrs. Bryan Donkin and Co. introduced the Perret furnace for the utilisation of this residue. Several other furnaces have since been patented in this connection, chief of which are the Wilton, Victoria, Crosthwaite, and Meldrum.

In all cases the furnaces named are for the most part constituted of a series of cast-iron air tubes built up of sections. Each section is provided with serrations, or is so arranged that a section forms a series of perforations with the abutting sections. A blank-end section is provided with each furnace so that the air for combustion of the fuel passes through the several serrations or perforations formed by the various sections when assembled. The air for combustion is delivered through the air tubes under pressure and is induced by the passage of steam usually at boiler pressure through suitable jets or nozzles. In the case of the Crosthwaite furnace these nozzles have an orifice $\frac{5}{16}$ inch in diameter.

Recent improvements in the design of the furnaces appear to have been directed to the number and size of the holes for the admission of the primary air, with minimum dust percolation, to the blast pressure, as well as to the provision of a secondary supply of air, these factors tending to a greater uniformity in the distribution and utilisation of the air.

Some details of the Crosthwaite's patent forced draught air tubes, with which the author has had experience, and the arrangement of bridges are shown in Fig. 1.

Coke breeze or dust, whatever is the correct term, possessing the characteristics given, obviously lies in a compact mass, presents considerable resistance, and renders uniform distribution of air at a reasonable pressure next to impossible. Indeed such a fuel bed is typical of the sand lute. Although porous, there is no uniform porosity and such pressures have to be induced by the operation of the steam blast as invariably lead to the introduction of an excess of air beyond that theoretically required for the combustion of the carbonaceous matter in the fuel.

Consideration of Fig. 1 will show that the primary air supply is a function of the pressure at which the steam blasts are operated and the resistance caused by the fuel bed. Of course the initial pressure created by the injection of air through the fuel bed is counterbalanced by the suction of

the chimney, and the point of equilibrium is usually immediately above the fuel bed.

The secondary air supply is alone controlled by the chimney draught. The correct regulation of the air is a matter of some difficulty, and has to be judiciously controlled according to the size and quality of the fuel, the porosity of the fuel bed, and its condition as regards clinker.

content of the waste gases is made strikingly evident in Fig. 3. Experience suggests that the depth of the fuel bed should be about six inches, and further, that it would be an advantage if the outer primary air ports were capable of adjustment so as to obviate the "blowing" of the fuel bed at points adjacent to the curvature of the boiler. Systematic and judicious clinkering plays an important part in securing efficient results.

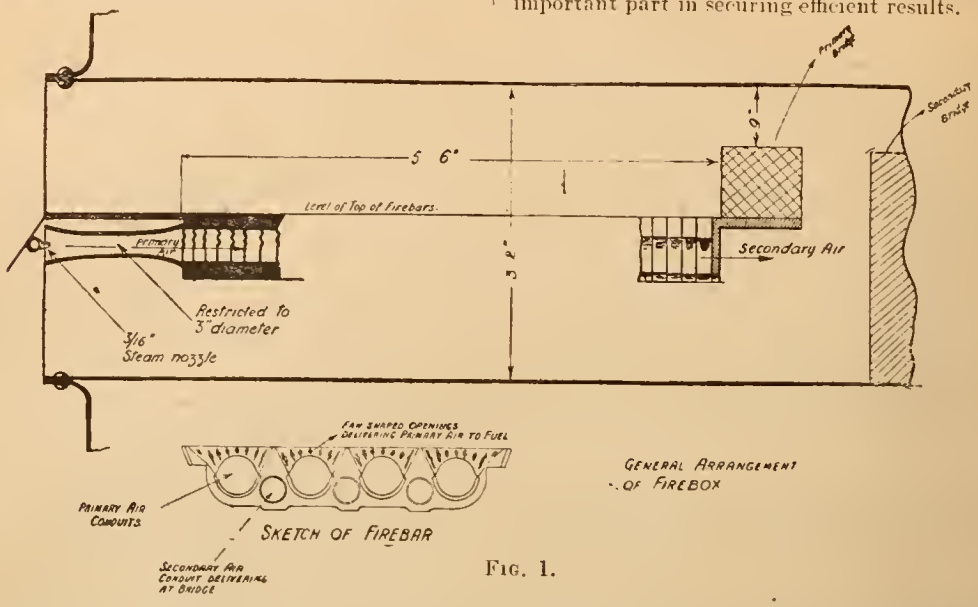


Fig. 1.

Many assume that the best results are obtained by admitting such a quantity of primary air as will lead to the formation of carbon monoxide, which can be subsequently burned to carbon dioxide. It has been suggested that this is the best way of ensuring a high CO_2 content in the waste gases.

The author's experience of the combustion of coke breeze in forced-draught furnaces does not confirm this view. Combustion would be very seriously retarded if an attempt were made to restrict the supply of primary air to such proportions as would lead to the formation of carbon monoxide. The resistance offered by the fuel bed is such as to necessitate the introduction of a quantity of primary air sufficient to promote very largely the production of CO_2.

It is usual to clinker the fires twice each eight-hour shift, but no irrevocable rule can be imposed. Much depends on the quality of the low-grade fuel. With coke breeze high in ash and moisture content, it is necessary to clinker three times per eight-hour shift. When working a series of nine or more Lancashire boilers, as is usual at the works in question, it is important that the clinkering operations should be conducted, as far as the quality of the fuel will allow, to a time-table.

If ten boilers are operating and the fuel is of average quality, it is seen that twenty fires have to be cleaned in 240 minutes. This allows twelve minutes per fire. It is usual to clinker and clean the left-hand fires in boilers one to ten in consecu-

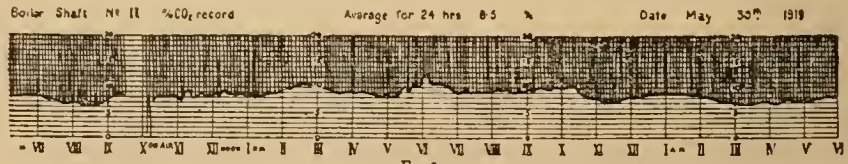


Fig 2

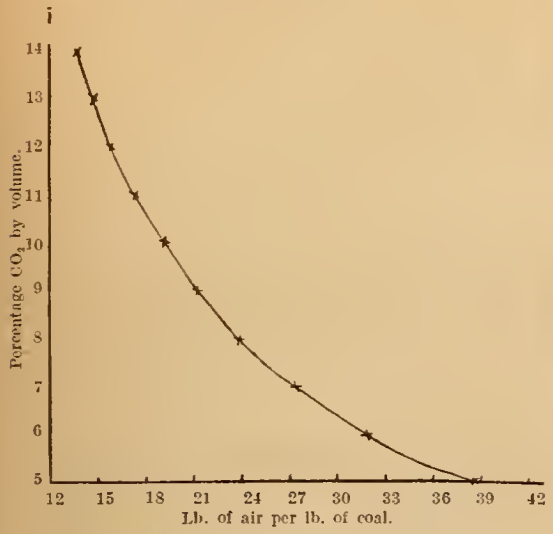
Analyses of the gases above the fuel bed when the latter is reasonably clean and under full blast show results as high as 16·5% CO_2 and 6·4% of CO. Continuous tests of the waste gases leaving the main flue (*vide* Fig. 2) indicate, however, that such a gas composition is not maintained for long, and further that dilution arises. The dilution was traced to the introduction of an excess supply of secondary air due to the imperfect fit of the ash-pit doors and to the absence of adequate provision for adjusting the quantity of secondary air admitted. Steps were immediately taken to remedy these defects in design, with greatly improved results.

The importance of directing attention to the CO_2

tive order, and then proceed in the same order with the clinkering and cleaning of the right-hand fires. The necessity for quick cleaning and re-charging is self-evident. It is important that the air-tubes should be kept clean. Fine dust passes through the perforations in the bars and must be removed periodically.

Another important factor contributing to the efficient use of low-grade fuel has reference to the productive capacity of the boilers. The author has had occasion to work boilers with coke breeze under intensive conditions, and it was apparent, during such periods, that the thermal efficiency began to fall; indeed, experience has clearly shown that

there is a distinct relationship between thermal efficiency and productive capacity. A Lancashire boiler which is capable of evaporating, say, 600 gallons of water per hour with best steam coal is incapable of being worked with coke breeze at a maximum thermal efficiency above a productive capacity of 400 gallons per hour.



A Comparison of Air Volume and CO_2 Content in Waste Gases.

Fig. 3.

It has also been found that the grate, as occasionally installed by the forced-draught specialists, is too long to admit of maximum thermal efficiency. By reducing the length of the grate by about 20% the temperature of the waste gases was reduced from 310° C. to 240° C., a lesser quantity of fuel was consumed, the capacity of the boilers was unimpaired, and the chimney draught was not prejudicially affected. As originally installed the length of the grate merely led to the combustion of extra fuel and an accession of the temperature of the waste gases—very little additional heat being transmitted to the water in the boiler, largely due to the absence of adequate surface area for heat transmission.

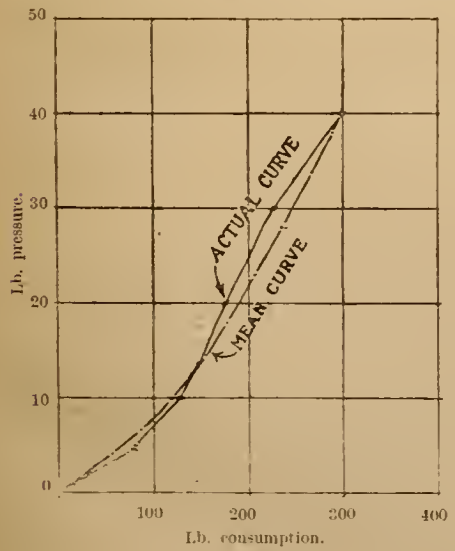


Fig. 4.

Adverse criticism has been frequently directed to the forced-draught system of low-grade fuel combustion by reason of the high consumption of steam in connection with the blasts. Various figures reputed to represent the steam consumptions under the conditions named have been mentioned from time to time. Fig. 4 furnishes data in this connection based on the discharge of steam at varying pressures. The diagram represents the mean of two distinct determinations.

In one case the steam passing one of the nozzles under varying pressures was condensed to water and measured, as such, at 15° C. The main steam pressure was 80 lb. per sq. in. These results are subjoined:—

Pressure in lb. per sq. in. thrown by the nozzle	Water in gallons condensed per hr.	Water in gallons condensed per hr. per boiler
5	1·0	8·0
10	1·58	12·6
15	1·95	15·6
20	2·16	17·2
30	2·8	22·4
40	3·4	27·2

To confirm the accuracy or otherwise of the above figures, a boiler was isolated and the steam, which was duly measured, was used exclusively for the jets of two other boilers. Results as follows were obtained:—

Main steam pressure	Pressure in lb. per sq. in. thrown by the jet	Consumption of steam per boiler equivalent to
80 lb. per sq. in.	40	29·8 galls. of water
—	20	16·9 " "

To what extent the steam used in the blasts for inducing the supply of primary air tends to form water gas (a mixture of carbon monoxide and hydrogen) is a matter which is at present under investigation. There are evidences that a portion of the steam so used is dissociated and forms water gas.

Although it is usual to produce blue water-gas by an alternate "blow" of air through hot coke in order to bring the fuel bed to a state of incandescence, and then a "run" of steam, undoubtedly, with a continuous steam-saturated, or steam-superheated supply of air, the Mond gas producer conditions are reproduced and producer gas is formed.

The importance of frequent and systematic cleaning of the side and bottom flues of the boilers as affecting the question of "drift" and its possible discharge from the chimney shafts cannot be too strongly urged. The entrainment of drift (that is fine dust and grit) by the products of combustion is a direct function of the velocity of the gases. If the gases in question exceed a speed of 6—8 lineal feet per second, then trouble from drift is inevitable. Obviously as the flues begin to accumulate dust, so their cross-sectional areas are gradually reduced with a consequent increase of velocity. If these constrictions of flue areas are coincident with a low CO_2 content in the waste gases, then two potent causes are operating in the creation of the trouble. It has been found necessary to clean the side and bottom flues each six weeks. This work can be effected during week-ends without seriously interfering with the boiler plant.

It was originally thought that the amount of drift could be diminished by eliminating the finer

breeze, and it was imagined that simultaneously a better fuel would result. A typical sample of breeze was screened, and the various percentages determined. Further, in each gradation the percentage of ash was ascertained by combustion in the usual way, with the following results:—

Size of screen in.	Remaining on screen %	Ash on dry basis %
7/16	19·2	34·10
¼	20·90	31·92
½	25·30	26·34
1/16	15·90	21·33
passing 1/16	18·70	24·14

These results are in distinct contradiction to what was surmised. It has generally been assumed that coke fractures by reason of occluded ash agglomerates, and that the coke at the surface of the fracture contains a higher ash content than the mass as a whole. The results obtained are certainly not in agreement with this theory, but rather suggest the variation to be due to varying hardness of the coke, probably owing to carbonising conditions. In this case the softer, more friable coke would undoubtedly contain more volatile matter—a condition which is usual in carbonisation. Naturally the ash would vary similarly. The increase of ash content of the screenings smaller than $\frac{1}{16}$ inch is doubtless due to contaminated dirt in this portion of the screenings and the removal of this fine material would be justified, not only from the point of view of the production of a more porous fuel, but also by reason of the possible mitigation of the drift nuisance. The above results were for the most part so extraordinary that careful check tests were applied, but these only afforded confirmation of the above data.

Attempts to increase the porosity of the fuel bed, and to admit of a better control of the air supply to the boilers, thereby reducing the possibility of the formation of drift, by using a proportion of broken coke, say about 50 % of the total, have not been attended with the success that was anticipated. True, a more porous fuel bed is secured and the conditions are favourable to the abatement of the drift nuisance, but unfortunately the financial results of the operation of the boiler plant suffer, as the loss due to unburnt clinker is not curtailed commensurate with the extra expenditure on fuel.

Using 52·9 % of broken coke with 47·1 % breeze the results were as follows:—

Fuel analysis.—Breeze (184·45 tons): moisture, 13·00 %; ash, 15·89 %. Broken coke (207·75 tons): moisture, 5·20 %; ash, 13·73 %. Average: moisture, 8·9 %; ash, 14·9 %; carbon (by difference), 76·2 %; calorific value (calc.), 11,000 B.Th.U. per lb.

Volume of softened water, 614,070 galls.
Less water "blown down," 24,030 galls.
Volume of water evaporated, 590,040 galls.
Weight of water per lb. of fuel, 6·7 lb.
Temperature of feed water, 57° C. = 135° F.
Average steam pressure, 100 lb. Abs.

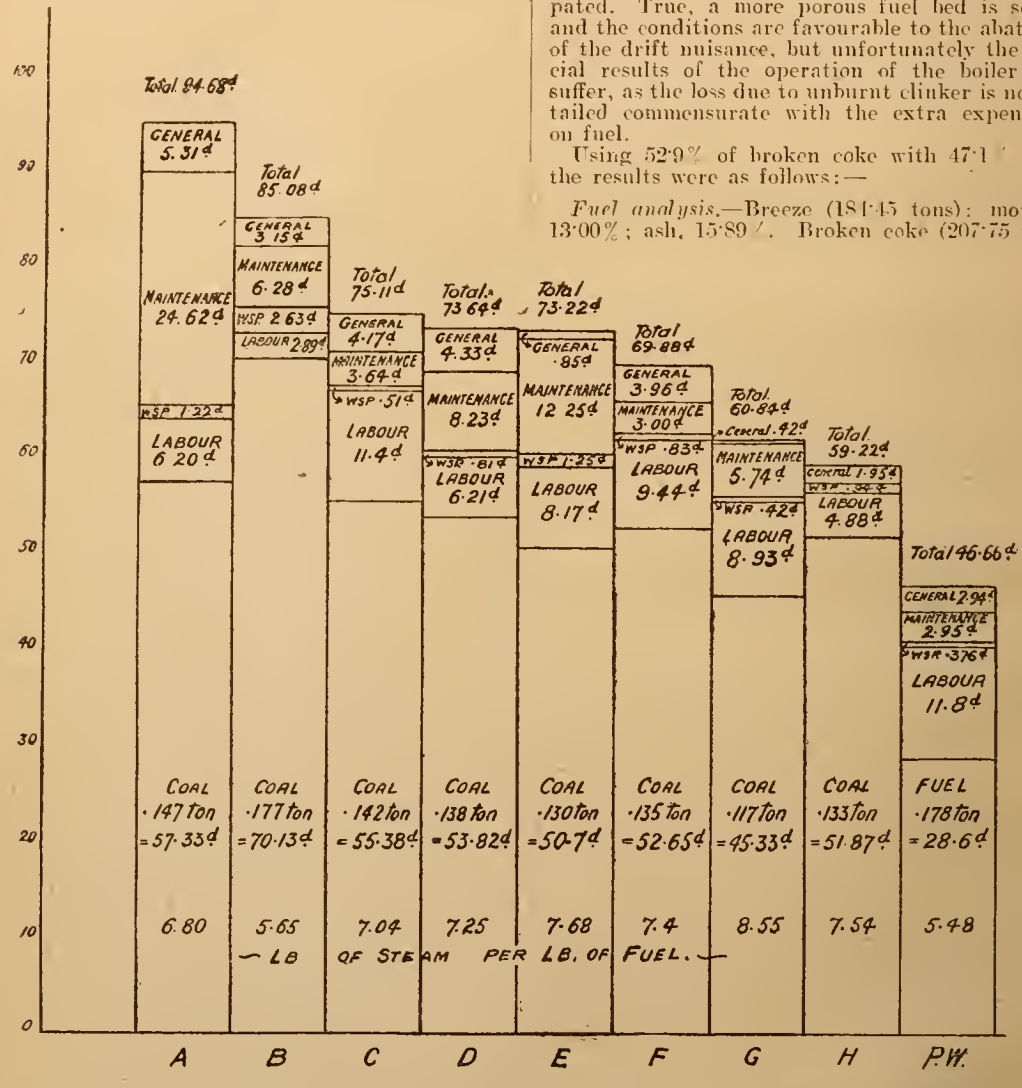


Fig. 5.

Temperature of feed water, 57° C.=135° F.
Average steam pressure, 100 lb. Abs.
Thermal efficiency, 65·8%.
Loss due to unburnt clinker:—
Ash in fuel, 14·9%.
True ash in dry clinker, 92·18%.
Clinker per lb. of fuel, 0·164 lb.
Carbon in dry clinker, 7·82%.
Loss of carbon in 0·164 lb. clinker, 0·013 lb.
Loss of carbon based on 0·762 lb. carbon, 12·5 %.

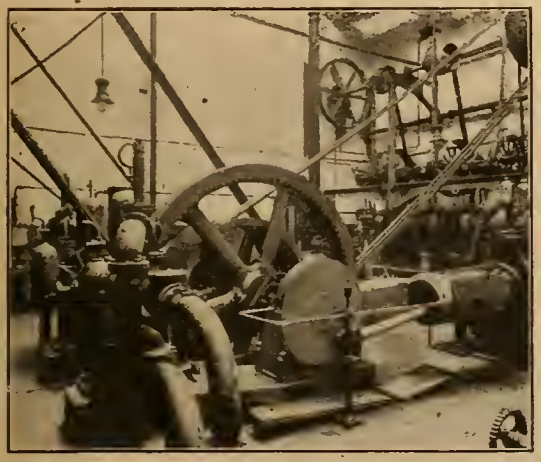
Using breeze exclusively the loss, over a three months' period, due to unburnt clinker was as follows:—

Fuel analysis.—Breeze (412·3 tons): moisture, 10·30%; ash, 29·31%; carbon (by difference), 60·39%; calorific value (calc.), 8800 B.Th.U. per lb.

Volume of softened water, 480,010 galls.
Less water "blown down," 17,030 galls.
Volume of water evaporated, 462,980 galls.
Volume of water per lb. of fuel, 5·0 lb.
Temperature of feed water, 55·5° C.=130° F.
Average steam pressure, 99 lb. Abs.
Thermal efficiency, 61·5%.

Loss due to unburnt clinker:—
Ash in fuel, 29·31%.
True ash in dry clinker, 87·50%.
Clinker per lb. of fuel, 0·335 lb.
Carbon in dry clinker, 12·5%.
Loss of carbon in 0·335 lb. clinker, 0·049 lb.
Loss of carbon based on 0·6039 lb. carbon, 20·4%.

Reference to Fig. 5, which furnishes comparative costs of raising steam, is interesting. The costs A to H represent published results of several Government factories. In order to render a comparison possible with the results obtained at Phœnix Wharf (the works under review) the cost of coal on the Government plants, instead of being calculated on the original basis of a flat rate of £1 per ton, has been computed on the price at which a similar quality coal could be bought delivered Phœnix Wharf. The price of 13s. 6d. per ton represents the price at which the low-grade fuel—coke breeze—is purchased from the gas works. In other respects the figures speak for themselves and demonstrate the economy resulting from the combustion of coke breeze when properly supervised.



It is impossible in the limits of a paper of this character to deal with several other important factors, such as (1) water softening and filtration, (2) preheating of the boiler feed water, (3) the necessity for a continuous supply of preheated water to the boilers, (4) causes of priming, and (5) the importance of the daily "blowing down" of the boilers, all of which contribute to increased thermal efficiency.

The photograph shows a view of one of the power plants, of which there are two almost identical units at the works in question.

At most sulphuric acid and sulphate of ammonia plants there are, for the most part, steam-operated pumps for boiler feed water, cooling water, milk of lime solution, gas liquor, and "devil liquor"; steam-driven air compressors, steam-driven self-contained centrifugals, and small steam-power units for driving the elevators and conveyors and other such plant. Very rarely is any attempt made to utilise the exhaust steam at these works, and, further, the several pumps and small power units are scattered and are usually situated in the midst of operations which are far from clean. These various units are inclined to be neglected, they become somewhat inefficient in operation, and maintenance and running costs are usually high.

The advantages of a centralised plant, as illustrated, are essentially:—

(1) Supervision charges are reduced to a minimum.

(2) Force-feed lubrication can be adopted.

(3) The pumps and other such plant are removed from the sphere of corrosive liquids and gases.

(4) There are minimum heat losses, due to the absence of several separate services.

(5) Economy in capital expenditure.

(6) A marked saving in steam consumption as the aggregate load warrants the installation of a condensing engine.

On the other hand it is conceded that the load at such a chemical works is not altogether a continuous one, but is only partially so, and obviously centralisation under such conditions has some disadvantages.

On the whole, the author strongly favours centralisation of power plant, believing that the loss incurred owing to a moderate load factor is more than counterbalanced by more economical running costs, reduced repairs and maintenance charges, and economy in initial capital expenditure.

It is regretted that the length of this paper precludes a more extended reference to the important aspect of power plant in chemical works.

In conclusion, the author wishes to express his thanks to Dr. Carpenter for his kind permission to publish the various data embodied in this paper. He also wishes to express his thanks to Messrs. W. A. Damon (B.Sc.), F. S. Evans, R. H. B. Lamprey, and O. W. Weight for their assistance in carrying out various tests and for determining the data and preparing the diagrams and charts incorporated in this contribution.

Discussion.

Mr. J. H. West said that the paper called attention to a very valuable and much neglected means of raising steam. It was valuable from the national point of view as using low-grade fuel. He had had some experience about six years ago with burning coke breeze under a battery of six Lancashire boilers in a chemical works, and he had been able to make comparative tests between that plant and another plant of four Lancashire boilers burning bitumen slack through underfed stokers. The two works had been making the same products, so that the basis of comparison was quite good. From these tests he could fully bear out the figures of cost given by Mr. Parrish, allowing for the great difference, of course, between pre-war prices and those ruling to-day. In his case the coke breeze delivered alongside in barge cost 6s. 3d. and the coal slack in the other works cost 13s. 3d. The cost of fuel in producing a ton of steam in the case of the coke breeze was 13d., whilst in the case of coal it was 20·5d., the cost of labour being 8d. and 6d. re-

spectively. The great trouble in using breeze was the choking up of the side flues with dust. It was best to clean them out every six weeks. That was sufficiently frequent to keep the velocity of the gases down. Very often the dust in the side flues was 2 ft. thick when they were cleaned. He had also adopted the system of cleaning out one fire of each boiler at a time; with six or more boilers there was a fire door open the whole time, because there was a great deal of clinker to be got out. That meant a great deal of cold air getting in and a certain amount of radiation loss in consequence. The author had raised an important point about the primary and secondary air. He had tried reducing the primary air to save steam on the jets, but that was apt to result in incomplete combustion, so that unburnt carbon monoxide might pass on in the main flue and cause explosions by mixing with excess air from other fires. He had got over the difficulty by increasing the primary air to the proper extent. These explosions were particularly liable to happen if any of the fires were banked owing to a temporary decrease in the demand for steam. To sum the matter up, the main advantage of coke breeze was its cheapness for the calorific value. At that time, and he fancied it was so to-day, gas works had very large accumulations of coke breeze which they could not dispose of, but if the demand were to increase largely the price would probably rise. Another disadvantage was the large amount of clinker to be handled and got rid of; in a London works where one had to pay to get rid of the clinker that was rather a serious matter; there would be about three times as much as from coal with 7% ash. The capital cost of a plant for burning coke breeze was 50% more for a given duty than that of a plant burning coal, because the boiler would only evaporate 400 gallons with breeze whereas it would do 600 gallons with coal. Finally, boilers burning breeze could not be forced to any extent if there were an emergency demand for steam.

The CHAIRMAN said he took it that the last speaker's remarks related to the use of breeze in the Lancashire type of boiler, and if that was so he quite agreed with what he had said, but it had always seemed to him a barbarous method of steam raising to burn breeze in a Lancashire boiler. With furnaces of the type generally used in large power stations for steam raising—the Babcock or Stirling type—the possibilities were much greater, and it had been found—not perhaps with breeze of the lowest grade, but with breeze containing a certain proportion of larger coke—that results could be obtained as regards output from the boiler nearly equal to those obtained when using coal.

Mr. H. M. RIDGE said it seemed that the author had used an excess of steam for blowing in his primary air; if that were so, it was most undesirable, because not only would there be too much cooling, but, with coke breeze, a considerable proportion of water vapour would pass undecomposed through the incandescent coke, so that heat would be lost at each stage. In the type of boiler illustrated in Fig. 1 with the fire bridge as shown, inter-mixing the secondary air with the gas and probably partially burnt gas from the fire grate, no really efficient result could be obtained in regular practice in his experience. He had found it necessary to interpose division walls and split up the current of gas to cause a more efficient mixing of the secondary air with the gas from the fire grate. The CO_2 diagram (Fig. 2) seemed to show approximately about 9%. At that figure there would be quite an appreciable amount of excess air to be heated, and the efficiency would be considerably increased by reducing that excess air. It would be of great interest if the author were to give not only the exact figures of the grate areas, but the quantity of coke and the weights of steam used per square foot of grate area, so that the figures could be compared with other results. Mr. Parrish had raised quite an interesting point about dust being carried forward as drift, and had compared it with mechanical pyrites burners. He could not agree with the author's figure of the limit to which it was necessary to reduce the gas velocity in mechanical burners. That depended to a very large extent on the design, and, working with a much finer material than the ordinary pyrites fines —90% of which, say, would go through a 40-mesh sieve—it was possible to use a higher gas velocity without having an appreciable quantity of dust carried forward.

The CHAIRMAN said that the explosion in the flues arose from the fact that as the fire was banked there was a thick body of fuel, and the small body of air going through was converted into carbon monoxide, so that if there was not an adequate supply of secondary air, or when the fire door was opened, an explosion generally occurred.

Dr. W. R. ORMANDY asked whether the experiments described in the paper were carried out on a Lancashire boiler. He presumed they were, because the author spoke of the main difficulty in dealing with coke breeze being the deadness with which it lay in the fire grates. That pointed to the need for some form of moving bar, and he believed that a fire-grate had been made of the moving-bar type such as was employed generally in the Babcock boiler, working with induced draught. He had been told that it was possible with coke breeze of ¼-in. mesh to burn from 60 to 80 lb. per square foot per hour. If that were true, then the problem of raising steam would be rather a question of what the boiler could do on the water side rather than on the fire side. With regard to the distribution of ash in the smalls from vertical gas retorts of the Glover-West type, in which steaming was employed, he asked whether the water gas manufacture, which took place in the lower or hot portion of the column of smoke, led to the separation of ash, particularly on the outside of the coke particles; whether, in fact, the process of steaming would result in the removal of a very considerable portion of the ash. It seemed to him, *a priori*, likely that in an ordinary retort where the mass was being heated by external fire, and hot steam was being passed over the coke, there would be a tendency for concentration of the ash on that portion. He did not know whether the coke referred to in these experiments was taken from a vertical retort with steaming, or from horizontal or inclined retorts. With regard to the secondary air it seemed to him that the ideal to be aimed at was the use of air in the primary at such a pressure that the carbon was burnt practically to carbon dioxide with a minimum amount of carbon monoxide and the minimum requirement of secondary air. With regard to the use of wet steam in jets, it was essential to have a standard plug gauge to test the size of the holes, because they very rapidly enlarged, and although on a test possibly the amount of steam used in that type of stoker might be only 2½ or 3% of the total steam raised by the boiler, a similar test carried out three weeks or a month later might result in 7 or 8% of it being used.

Mr. PARRISH, in reply, said that he should not recommend the reduction of primary air except so far as the outer ports were concerned. If the primary air were reduced, the incombustible matter must of necessity increase and an explosive mixture would be formed. The question of the disposal of clinker was one which certainly needed consideration. The clinker arising from the combustion of coke breeze was about 2½ to 3 times the quantity resulting from the ordinary bituminous coal. So far as the extra capital expenditure on the boiler

plant was concerned he did not quite agree with the figure mentioned by Mr. West of 50%. Some calculations which he had made revealed the fact that not more than 25% extra capital expenditure was incurred. He agreed with Mr. West as to the difficulty of forcing the plant, and therefore there must be sufficient plant available if the load were likely to be variable. In reply to Mr. Ridge, it was impossible to burn breeze unless there was a certain pressure in the primary supply, and the only way to get that was by using certain quantities of steam. Taking the ordinary setting of a Lancashire boiler, continuous tests made at the outlet of the boiler in the drop flue showed that they were getting 14·3% of carbon dioxide between 3 and 4 o'clock; 15% between 4 and 5 o'clock; 13·9% between 5 and 6.30 o'clock; and 16·9% between 6.30 and 8.30; these CO_2 contents were accompanied by 1·4%, 1·1%, 1·1%, and 2·67% of carbon monoxide in the four cases respectively. Dr. Carpenter had suggested that a test which he had given here did not correspond with the figures which were illustrated in Fig. 2, that there was an increase in the CO_2 in the latter case. He had decided to carry out a series of tests right along the boiler flues to ascertain the point at which excess air was being admitted. The type of bar which was supplied by the Crosthwaite firm made quite inadequate provision for closing the door of the ash pit immediately below the forced draught furnaces. It had therefore been closed by improvised means; it had then been found that the CO_2 content gradually increased until the figure he had given was reached.

Mr. Parrish said that was so. Even though all leaks and chinks in the brickwork had been made perfectly tight the content of CO_2 in the waste gases could not be increased much beyond 10%. He had therefore decided that a determination should be made right through the whole travel of the gases, and although he had not completed that determination he was certain he was getting very efficient combustion of the material and that the probabilities were that unburnt carbon monoxide might possibly account for the somewhat low CO_2 content. The size of the secondary air ports was probably such as to lead to an excess of secondary air for the combustion of any carbon monoxide formed. It seemed as though they were introducing too much secondary air and that that excess, which was a function of the chimney draught, and the size of the holes provided in the forced draught bar, accounted for the low CO_2 content. It had therefore been decided to shut off two of the secondary air ports, and the determinations which he had just mentioned were the result of that investigation, *i.e.*, the CO_2 content was brought up at the back end of the flue to 15%, and the carbon monoxide varied between 1·1 and 2·67%. The oxygen under those conditions was only 2%, so it appeared that although the amount of secondary air could be curtailed, it could not be curtailed to the extent that had been anticipated. By careful adjustment of the secondary air ports it was probable that a CO_2 content approaching 14% would be obtained; that would be a very satisfactory result with a low-grade fuel varying in ash content from 15 to 30%.

The Chairman said that, as far as he could understand it, the diagram in Fig. 2 was put forward as showing the CO_2 content on the main outlet of the boiler setting, and perhaps also the inlet to the main flue, and Fig. 3 showed the composition of the main products of combustion as they left the furnace tube before they were diluted by leakages from the setting.

Mr. H. M. Ridge said there were two possibilities; he had found them in a parallel case himself. One was that the gas was being cooled too far before secondary air was admitted, so that complete combustion of the carbon monoxide did not take place; the second was that trouble might arise through insufficient mixing of the secondary air with the first products of combustion.

Mr. Parrish said that the temperature of the gases varied according to the state of the fire, and whether clinkering was taking place or not, and he did not think it could be suggested that there was any cooling, because the temperature of the gases just behind the bridge was 617° C., and that temperature was reduced during clinkering to 420°—430°, but then it was immediately raised again to 610°. The temperature was 610° at 8.30 when the fire was in full blast and working well; at 8.45 it was 565°; at 9 o'clock 560°; at 9.15 it was 585° and at 9.30 550°. That was quite a good temperature from a material of the character used, and yet the waste gases were leaving at 200° C. There was some obscure point in connection with the combustion of this low-grade fuel, and he thought it depended upon extreme care in regulating the primary and secondary air. Further, he was certain that water-gas was formed and their determinations had led them to believe that at least 20% of the steam which was used in the blasts went to form water-gas. The combustion of that extra carbon monoxide and hydrogen was a matter which necessitated care in regulating the secondary air supply. Mr. Ridge had also raised the question of gas velocity in relation to the mechanical burners and suggested that there was no necessity to reduce the velocity of the gas to 4 feet per second. In his own experience in connection with mechanical burners he had found that that figure applied very well not only to Norwegian pyrites fines but also to Spanish pyrites fines, and as far as the dust in connection with spent oxide furnaces was concerned, which was lighter, it was necessary to have a lower velocity if it was desired to eliminate the last traces of dust to get a satisfactory Glover tower acid. In reply to Dr. Ormandy, his experiments had been carried out with a Lancashire boiler. He had had an opportunity of inspecting an installation where a moving grate had been adopted for the combustion of coke breeze and where induced draught under a pressure of about 5/8ths water gauge had been used, but the results had not been so satisfactory as his own. Considerable attention had been directed to the wearing of the jets, and he had found that after twelve months the enlargement was very small indeed. It depended upon the material of which the jets were made. His personal view about the scientific combustion of coke breeze was that it should be burned outside Lancashire boilers in a type of producer, and that led to three conditions: a modified type of step grate was required; the producer must be arranged in such a way that there was pre-heating of the low-grade fuel, which was essential; and the step grate should be such that the clinker could be removed almost automatically. Under these conditions he was certain that this material could be burnt to advantage and much more economically than was represented in the figures furnished in the paper.

The Chairman said that the author had described an economical method of raising steam arising from the fact that the fuel he had used was very low in price. He had really summed up the whole question in his last remarks, *viz.*, that this type of fuel should not be burnt in a Lancashire boiler at all. It should be gasified externally by a producer properly designed for that purpose, and the gas fed into a boiler of some type, such as the Bonecourt. A great deal of coke breeze was being produced all over the country in increasing quantities, because the coke which was now being produced was much more friable than the harder coke produced in the old-fashioned retort settings. There had always been a great scope for a producer which would burn breeze; there certainly was an increasing use for one to-day. That was a problem the

solution of which would be of very great value from the point of view of conserving our fuel resources. With regard to one question raised by Dr. Ormandy, he said that the temperature in the lower part of the vertical retort was very low. The retort was made of cast iron, and he could not imagine that there would be any difference in the ash content of the coke at the edge or extremity compared with the centre. He imagined that the coke had been fairly broken up by the time it got to the lower part of the retort, and that the steam really played all round it. Otherwise he did not think the results would have been achieved, at any rate as regards ammonia production, which had been reported from time to time.

A paper by Mr. H. Martin on "Electrical Supply in a Chemical Works" was taken as read.

NOTES ON THE ECONOMIC MANAGEMENT OF SMALL BOILER PLANTS.

BY J. W. HINCHLEY, WH.SC., A.R.S.M., F.I.C.

In many small chemical works where the demand for steam is irregular, and in those factories where steam or power costs are small in comparison with the total cost of production, the steam boiler plant is often neglected, and, with the exception of the regular inspection by the boiler insurance company, is left entirely to the stoker.

This habit of mind on the part of the management may be due to several circumstances. A common cause is the limited supply of controlling "brains" or the overloading of those in use, with the result that what can be left alone is left alone. Often the possibilities of saving in other directions are so great as to attract all effort; but generally most managers feel that attention to the boiler plant does not give an adequate return. It is sad to state, however, that personal jealousy and ignorant conceit often preserve a bad state of affairs in the boiler house and other places, when the rest of the factory may be well managed.

During the recent coal difficulties another factor —restriction of supply—has compelled most firms to pay attention to the problem, but success in small plants can only be achieved by educating the stokers and giving them an incentive to economical working. The recent increase in the price of coal will make everybody contemplate change.

It is easy to add accessories to boiler plant and make definite savings, and from a national point of view these are justified by a bare return, but in many cases it is possible, without any addition to the plant, to save the whole of the wages of the stokers by reasoning educational talk and by giving them a material benefit from their more efficient work.

The ordinary equipment usually consists of one or more hand-fired Lancashire or Cornish boilers with chimney draught and a few simple accessories. It is common to find that an injector is relied on for any irregular water feeding, while a pump attached to the main engine deals with the water for the power demand. In the best plants a separate "Worthington" or similar feed pump is provided. Economisers, feed water heaters, and purifiers are not so common.

In many cases an increase in the boiler capacity has become a constant worry and need, when a little education on the part of the stoker would prove that there was ample capacity.

A steam boiler is a "high pressure continuous still," and should be treated as such. The effect of intermittent hand-firing in tending to make the stoker adopt such discontinuous methods generally must be resisted if he wishes to secure the highest efficiency.

The systematic chemical and physical examination of the fuel and the flue gases, the latter at different periods in the operation of the boilers, is not a difficult routine matter to establish even in a small chemical works, but unless the results are made intelligible and discussed between the stoker and the chemist no real improvement may be expected. The draught available at each boiler should be considered by the stoker in firing. In those cases where low chimneys are provided (and a 60-foot chimney is occasionally found!) a very thin fire is essential, and its management calls for constant attention on the part of the stoker to get a reasonable amount of coal burnt efficiently.

The effect of heat transmission on the efficiency of boilers is of paramount importance, but the possible enormous variation of the rate of heat transmission is still hardly appreciated.

The outstanding importance of the heat transmission by radiation from the fuel bed should be insisted on. The stoker in firing should destroy as little as possible of the area of the incandescent fuel bed. The length and shape of the firebrick bridge may be increased with advantage both to combustion and heat transmission.

The improvement of heat transmission on the fire side by increasing the velocity of the hot gases is usually not possible with the type of plant we are considering, although the reward is most attractive. The importance of the heat transmission on the water side of the boiler plate has not been adequately recognised in the past.

The simplest experiment will show that the rate of heat transmission (per degree of temperature difference) to boiling water may be as much as four or five times the rate to non-boiling water at the same temperature. The rate of heat transmission depends on the amount of mechanical agitation produced. For the maximum rate of heat transmission the water must be kept boiling vigorously. With very high temperature differences this rate of heat transmission (per degree of temperature difference) falls off again, so that the average rate for a given amount of evaporation is higher under steady boiling conditions than under variable and non-boiling conditions.

In hand-fired boilers the combustion of nearly 4lb. of coal per hour per square foot of heating surface usually gives the maximum efficiency. Now the equivalent of the combustion of ¼ lb. of coal per hour per square foot of heating surface is the maximum rate at which no boiling takes place. It might appear therefore that the non-boiling condition rarely occurs, but where both fuel and water are supplied intermittently, this condition is produced regularly in many factories. It will be obvious, therefore, that the supply of fuel and water to the boiler should be made as continuous as possible to obtain the best conditions of heat transmission.

The formation of scale in the boiler during work has a most serious effect on heat transmission, and may reduce the capacity just before the cleaning period and occasion loss. The use of substances to prevent the formation of adhesive scale is generally advisable even with softened water. One of the latest of these materials, graphite, if used in the highest purity (85% carbon), is extremely effective. After cleaning, the boiler is painted internally with the graphite made into a cream with water, and subsequently about ¾ lb. added per day. In several cases the presence of graphite in the steam system has revealed what was quite unsuspected, bad stoking and priming. The general rule of the good stoker is to keep his fire in constant adjustment to the steam demand, maintaining it in such a condition at the lowest periods so that by fully opening the damper he can obtain in a few minutes the maximum rate of combustion on the fire grate. At times of low demand the water level and steam pressure should be kept at their highest points,

with the feed-pump working at its lowest rate. An increased demand for steam is shown by a drop in pressure and a fall in the water gauge. The opening of the damper and acceleration of combustion speedily equalises matters, and when the pressure ceases falling the feed-pump is accelerated to maintain the water level. A rise of pressure, on the other hand, would demand the closing of the damper somewhat, followed after some few minutes by a reduction of the speed of the feed-pump. Should the demand for steam over a period be such that in spite of maximum combustion the pressure falls too low for adequate service, some alteration or addition to the plant becomes essential. The grate may be increased in area (generally with reduction in efficiency), or a heat accumulator or a new boiler may be installed.

On the other hand, the particular plant taking the sudden large supply of steam may be controlled to reduce its rate of working for the period of heavy steaming without any loss.

A continuous feeding pump capable of continuous adjustment is essential to economy. As a rule injectors should be removed. For boiler feeding they are inefficient through being intermittent.

It is obvious that to make this economy permanent it will be necessary to incite the stoker to constant interest, and the best way to do this is to allow him to share the saving he is able to effect by his vigilance. The simplest and only good method consists in measuring and recording the amounts of coal and feed water supplied, and paying the stoker monthly one-half of the value of the fuel saved on an agreed basis. In most cases there are complications, such as the return of water to the boiler through closed heating systems, but it is not difficult to devise a scheme which will enable one to give every satisfaction to both parties and secure continuous economy.

Discussion.

The Chairman asked what was the author's objection to the injector.

Prof. Hinchley said that owing to the intermittent action of the injector the pulling of the water often ceased for a short period with a rise in the temperature of the waste gases, and there was a consequent loss of efficiency of the boiler during that period.

The Chairman asked if it was not possible to keep an injector working regularly in the same way that a feed pump did.

Prof. Hinchley said it was not. A pump could be kept following the fire.

The Chairman said that whatever might be the disadvantages of the present industrial conditions, we had a much more intelligent workman than was the case 25 years ago. He believed that Prof. Hinchley was right that the more their employees could be interested in the particular work they had in hand, the more efficiently they were likely to carry out their operations. In the carbonising of coal of late years their methods in this respect had changed considerably. The man who had supervised those plants 25 years ago had been a stoker who, perhaps, had known a little more than the average stoker, or perhaps had been more steady and reliable at his work. Apart from that he did not think he had had any other special qualifications, but the man in charge of these plants today could answer intelligently questions with regard to the combustion, the part played by the secondary air, the importance of its regulation, and the importance of the indication of the CO_2 in the waste gases as being a guide to efficient working. To what extent that state of affairs would be a set-off to the present high wages and general dissatisfaction it was difficult to say, but they could only hope that a great deal of the extra expenditure would be recovered by getting him to do his shorter day's work more intelligently than was the case in the days gone by.

Mr. H. Cheetham, referring to the author's suggestion as to sharing the saving with the stoker, said that in the Lancashire district, where coal was mostly used in the cotton mills, it was a common practice for the stoker in charge of the boilers to get a commission from the coal dealer, and this was an inducement to use more coal rather than less. He did not know how far that system was practised in other industries.

The Chairman said that there again he thought his remarks applied, because the more intelligent they could make a workman and the more self-reliant and independent he was, the less he would rely on these side arrangements for providing him with what he would probably call a living wage. He believed that in the future they would have a better class of man who would scorn to do many of the things which some years ago had been quite common.

The Chairman, in closing the Conference, said that all engaged in the chemical industry realised the increasing importance of chemical engineering. Among the many tasks before them was that of bringing together all those whose practice was mainly engineering and those whose practice was mainly chemical. There was no doubt that the position of the chemical industry was due very largely to the completeness of the collaboration between the engineer and the chemist. The greatest difficulty in the past five years had been in taking the fullest advantage of the large stores of engineering knowledge of the country and in bringing them in towards the chemical industry. That was a work which the Chemical Engineering Group had set out to perform. They had also set a very good example in not attempting to form a separate society or organisation, but in associating themselves with the Society of Chemical Industry. If they were successful—and he believed they would be—it opened up great possibilities with regard to other branches of the chemical industry.

SECOND CONFERENCE.

THE TRANSPORT AND DISTRIBUTION OF LIQUIDS IN CHEMICAL WORKS.

NEWCASTLE-ON-TYNE, DECEMBER 15, 1919.

The CHAIRMAN (Prof. H. Louis) welcomed the conference to Newcastle in general and to Armstrong College in particular, and expressed the regret of the Principal of the College (Sir Theodore Morison) at his absence. For his own part, he (the Chairman) was pleased to see them up in Newcastle. It was not a lovely town; it was a dirty town, a grimy town, but a business-like town, and engineers, at any rate, should feel at home in the atmosphere of coal dust and smoke which was a token in some measure of engineering activity. He did not need to remind them that Newcastle had been the pioneer of not a few chemical industries in the past, and was still holding its own with most other parts of the country. In the college he was particularly glad to see them, for the science to which they perhaps devoted most attention was chemistry, and, on the other hand, the department of engineering had made a well-merited reputation. They were, therefore, as fitting a body as any to receive and appreciate a visit from chemical engineers. When the much-needed expansion of the college took place, as he hoped it soon would, he was very anxious that a home should be found for chemical engineering, or whatever term they might give the subject. He did not doubt but what the authorities were giving serious attention to the matter. He had received a telegram from Prof. J. W. Hinchley, Chairman of the Group, stating that it was impossible for him to attend owing to illness, but wishing the gathering every success.

The subject selected for the conference was one of the greatest importance indeed to everyone connected with chemical engineering. The problem of elevating liquids was one of the oldest that engineers had had to solve. The simple problem of water pumping might be said to have been fairly well solved by mechanical engineers. The chemical engineers, however, had a more difficult problem before them. They were beginning to appreciate that mechanical methods must be introduced into chemical works. Chemical works had grown chiefly by the work of the chemists themselves, but in some instances, especially in that district, engineering had been conspicuous by its absence. There had been, however, before the war a movement for the introduction of engineering into chemical works, which had received acceleration by the necessity of the past five years for intensive production. The price and the scarcity of labour was making it necessary for the chemical engineer and industry generally to employ more and more mechanical methods of doing work. For the special subject being dealt with by the conference the need was remarkably conspicuous. There was great difficulty in the problem of having to pump fluids that might be highly corrosive, of a high temperature, specially mobile, specially volatile or containing solids in a state of suspension. The problem was one that differed from those in ordinary engineering. The solution had occupied some of the best brains in the country, and the way in which the problem had been attacked and the success achieved was indicated by the specimens of chemical engineering before them, and would be further elucidated by the papers to be read during the conference.

THE ELEVATION OF ACIDS BY THE KESTNER PATENT AUTOMATIC ELEVATOR.

BY J. ARTHUR REAVELL, M.I.M.E.

The use of the acid egg as a means of raising liquors in chemical works is well known. The egg is filled through the inlet and pipe, and when full the compressed air is admitted. As soon as the air pressure rises to the required amount, the acid is blown out through the delivery pipe. It will be at once seen that the whole success of the operation from the point of view of the quantity of air used depends upon the operator. Usually he knows from habit just how long it takes to empty the egg. Experience has shown, and, indeed, it has been admitted on all sides, that this method tends to great loss of air, and is generally inefficient.

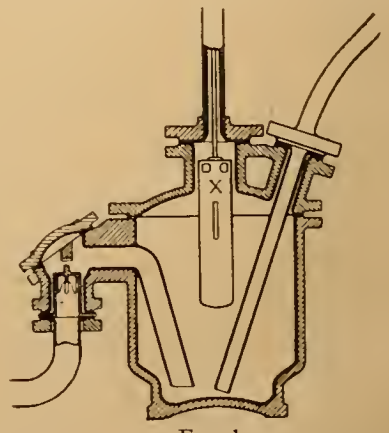


FIG. 1.

The Kestner elevator was designed to overcome this waste and to do away with the labour required to operate the valves. This question of labour is of the utmost importance, particularly now when wages are continually rising and working hours shortened.

The three points of importance in dealing with the problem of raising acid in chemical works are:— 1, Simplicity; 2, reliability; 3, economy in labour.

The Kestner patent standard elevator is shown in the accompanying illustration with the body in section.

The method of working is as follows:—Acid flows into the body of the elevator through the inlet valve, which is coupled to a feed tank placed above the inlet valve. The size of the feed pipe and valve is such that the acid rapidly fills the elevator body. As soon as the acid rises to a pre-determined height in the body the float operates. In order to obtain a quick action it will be noticed that the float is carried into the narrow portion of the top cover, and the acid flowing in rapidly fills this, causing the quick return required.

By examining the sectional illustration the movements whereby the air is admitted and exhausted are clearly seen. The lever, C (fig. 2), works on the

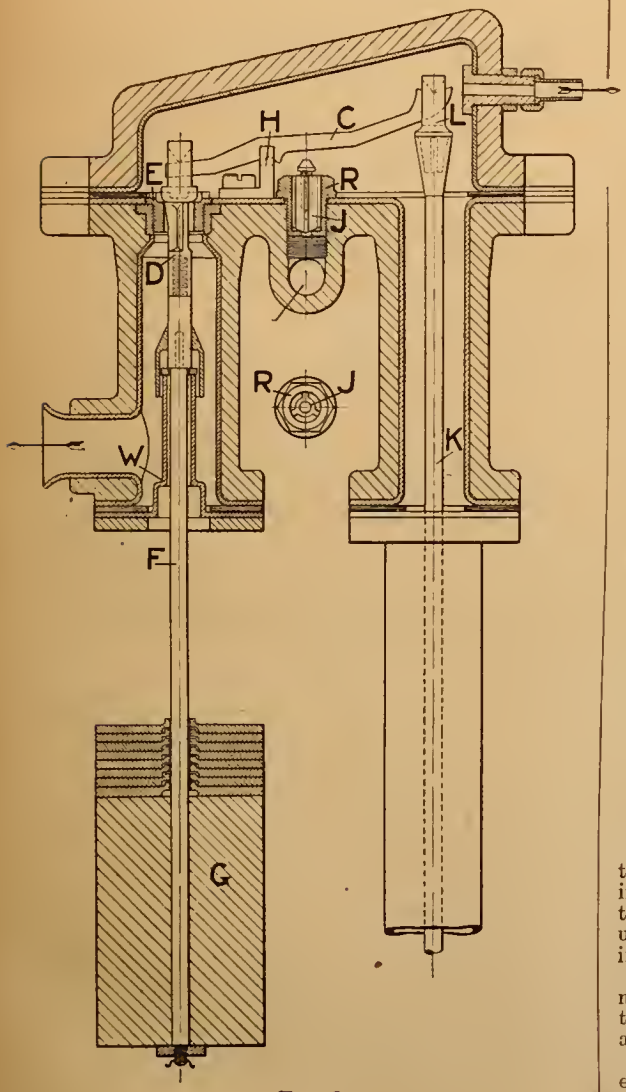


Fig. 2.

fulcrum, H, and the rod, K, which is coupled to the float, rises when the body is full. This at once releases the pressure from the air valve, R, and air is admitted into the head, passing down the stand-pipe into the body. At the same time, the pressure of the air closes the air exhaust valve, D. The compressed air blows the acid from the body up the delivery pipe to the receiving tank. The lever has at the opposite end to the float rod a balance weight rod, F, at the end of which balance weights are fitted to counterbalance the weight of the float. As soon as the acid is blown out of the body, the float comes back to its original position and the exhaust valve opens at once, allowing the air to exhaust. The acid inlet valve then opens, and the cycle is repeated. The movement of the lever is very slight, the air valve having a travel of only about $\frac{5}{64}$ in., so that the wear and tear is infinitesimal.

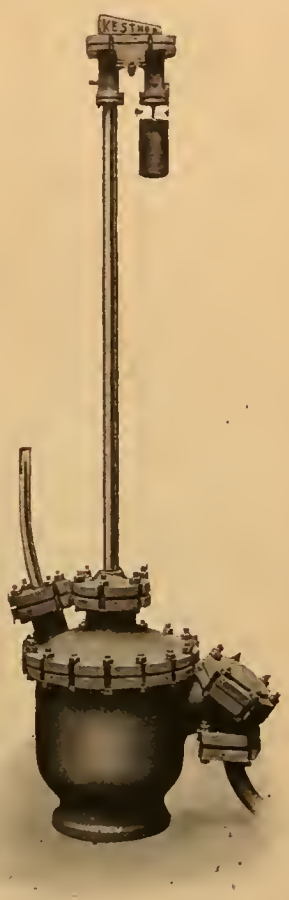


Fig. 3.

The stand-pipe should be of sufficient length so that the elevator head is above the level of the acid in the feed tank, thus preventing the flooding of the head with acid. The elevator can then be left under any conditions, and is ready for work immediately air is turned on.

These elevators can be constructed in cast iron, mild steel, mild steel homogeneously lead-coated by the Kestner process, lead lined, cast regulus, and also in potware.

Illustration 4 shows a patent acid elevator in earthenware, for pumping nitric acid; the special feature is the method of connecting the float to the lever by means of a wire. Originally this wire was of platinum, but during and since the war we have used a special alloy.

The acid elevators already described are those which work intermittently, the same as the ordinary acid egg, excepting that they are automatic in operation. It is necessary, however, for delivering acid into sprays, and for certain other purposes, that the acid should be delivered continuously. The

Kestner Patent Continuous Elevator was, therefore, designed for this purpose.

Illustration 5 shows a front elevation of one of these elevators. The lower portion consists of two bodies which can be constructed in cast iron lead lined, or unlined, as required, or they can be constructed of potware.

One of these bodies is slightly larger than the other to contain the float. The float is operated by means of a simple valve shown on illustration 6. Although this may appear to be complicated, in reality it is very simple indeed, and consists of a taper plug type valve operating in a valve box, both of which are made of potware. The apparatus operates as follows:—The air is delivered into the head at the opening H. The plug valve, R, is arranged with four ports which communicate with the opening marked 1 on the horizontal plane and 2 on the vertical plane. As the float rises, owing to the inlet of the acid, the wheel, F, is rotated until the trigger, K, which operates in a slot in the wheel, comes in contact with the wheel. This then moves over B and causes the weight, E, to fall with a sharp motion, thus operating the valve, R, quickly. This operation turns on air to the cylinder that has just filled, and shuts it off from the cylinder that has just been emptied, exhausting this to atmosphere. There are two openings for each cylinder. For one cylinder the diagram shows these at 1 and 1A. Both these connect in a common pipe to the cylinder, 1B. If, for example, the valve has just operated on No. 1 cylinder due to it being full, then the compressed air enters through 1 into No. 1 cylinder, and the exhaust from No. 2 cylinder leaves through pipe, 2B, by way of the valve, 2A, and *vice versâ*, each cylinder filling and emptying alternately.

These elevators, which have been used for discharging acid, through sprays at 40 to 60 lb. pressure on the sprays, are simple in operation and have no working parts revolving in acid, the only parts subject to the acid being the inlet and outlet acid valves.

No doubt questions will be asked regarding the wire for supporting the float as, of course, in this type of apparatus the float wire enclosed in a pipe cannot very well be used. Before the war this float wire was made of platinum, and no difficulty was experienced, as the gland is of particularly simple construction, packed with a special packing which has been most successful.

When the war came we were at a loss for a little while to procure a suitable wire in place of platinum, which was unobtainable, and at last found a progressive firm in this country who, after much experimenting, produced for us an alloy which resisted the action of any acid, and had the advantage of being extremely fine. It was proved that the finer the wire used, the more successful were the results. The diameter of the wire used is 0·8 mm.

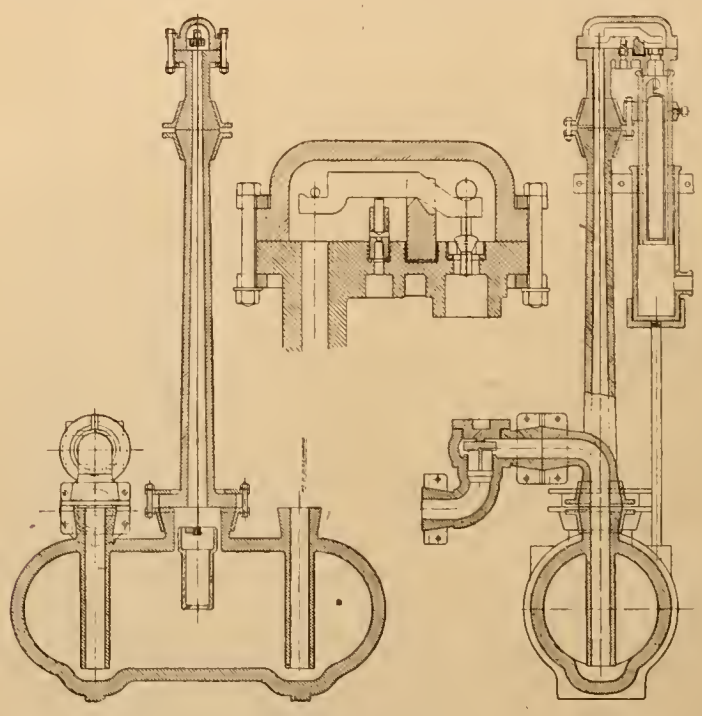


Fig. 4.

There is a great advantage obtained in the use of elevators that are operated by compressed air, namely, that a very different type of recorder has been invented by Mr. Kestner, whereby a record of the work done by each elevator can be obtained. The recorder is attached to the head of the acid elevator, and every time a charge of acid is delivered, the record is made on the dial.

On the continent, where labour-saving devices are used more extensively than here, and where perhaps such records are more exactly kept, large numbers of these recorders are in use, and by their installation the management can tell exactly how much acid has been delivered by each elevator.

Having described the Kestner Automatic Elevators, it will be interesting to see how far these machines fill the three points of vital importance to a chemical works which I have previously set out.

1. The first point of importance is simplicity. There is nothing in the Kestner Automatic Elevator that is not absolutely simple. One of the criticisms very often levelled at the apparatus, and one that will no doubt be raised here at this conference, is the question of the float.

This point is always raised by people who are ignorant of the nature of the float used in the Kestner elevator. It is because floats of different kinds are used by steam trap makers, which are constantly giving trouble. In a number of lifting

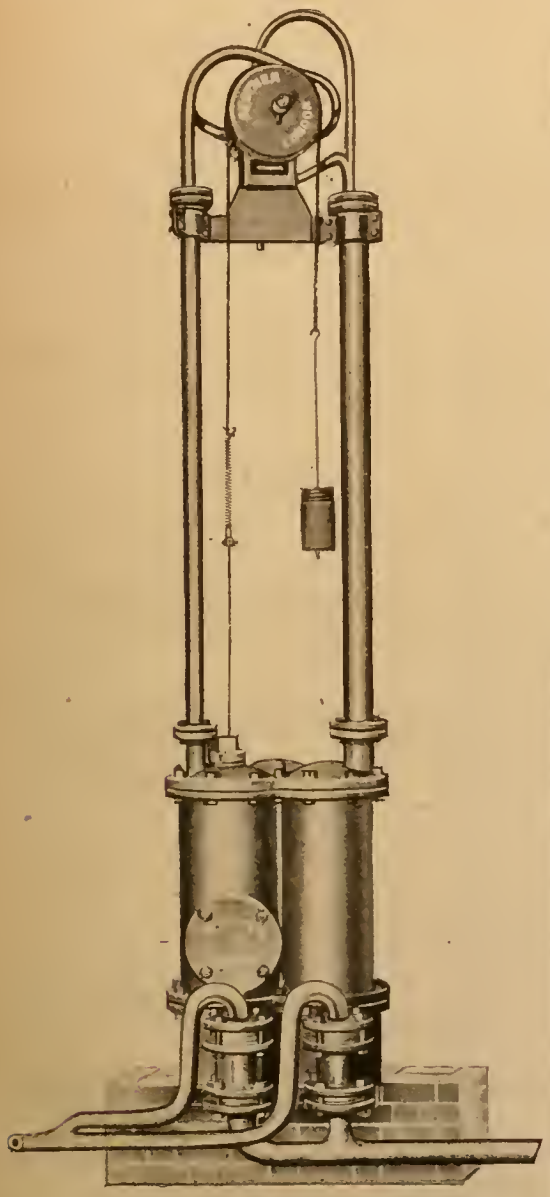


Fig. 5.

traps, with which the writer is familiar, floats are used to operate the valves, and they are continually giving trouble. This lifting type of trap originated from Germany, where large numbers are used.

The Kestner float is not an air-tight vessel. It is merely an open vessel which is filled with acid, so that there is no question of the float giving out, and, in fact, in all the designs of elevators in use no trouble is ever experienced in this connection.

The operating parts in the head of the elevator are out of the way of the acid, and practically the only pieces that need renewing from time to time are the two valves, the one for the air inlet and the other for the air outlet.

Some of these elevators have been continuously in operation in chemical works for over fourteen years, and the cost of upkeep amounts only to some few shillings a year.

As makers both of direct-acting pumps and centrifugal pumps for acids, we know ourselves that there is no comparison as regards simplicity between this automatic elevator and any type of acid pump.

2. The next point is reliability. Most processes in which the elevation of acids is necessary demand a method that is absolutely reliable, even though it cost a little more either in operating expense—that is, cost of power—or first cost. Happily this reliability is obtained by the Kestner Automatic Elevator without increase in either working or capital cost.

If you compare the reliability of an apparatus pumping weak sulphuric acid, say, for instance, a centrifugal pump running at 800 to 1000 revolutions per minute, with an acid elevator operated by compressed air which operates once every two to five minutes, it must be admitted that the elevator scores on the point of reliability.

I am free to admit that the pump for this purpose is still in its infancy, but up to the present on the point of reliability there has been nothing designed for pumping weak sulphuric acid to compare with the automatic acid elevator.

3. The third point, which is particularly important in these days, is the cost of labour. In the case of centrifugal pumps, or direct-acting pumps, they must be run either by direct coupling to motors or by belt. In the case of belt drive, you have the constant attention of line shafts, belting, etc. In the case of direct drive, you have the constant attention to the high-speed machines, looking after lubrication, packing of glands, and so forth, all of which involve skilled men, that is to say, first-class fitters. Nothing of this kind is necessary with the Kestner Automatic Elevator. The machine, as already explained, can be run for months without any attention. There is no lubricating to be done, and when new valves are necessary these can be easily replaced by the ordinary shift man, as it does not require a skilled fitter.

Taking into consideration the class of labour employed in chemical works, the working cost of using centrifugal pumps as compared with elevators must from this point of view be greatly increased.

A word or two on the importance of pipe connections will be of interest. The delivery pipe from an elevator should be of the size required to give the liquor a proper velocity. The pipe must be taken direct from the delivery of the elevator to the highest point to which the acid has to be carried, always rising, and never on a horizontal plane.

As the motive power behind the liquid is air, it will be seen at once that if a horizontal pipe is used, the acid will tend to flow along the bottom half of the pipe and the air to escape over the acid at the top of the pipe. The result is loss of air and the flowing back of some of the acid into the elevator body.

There is no doubt that if the whole problem of the elevation of all kinds of corrosive liquors is broadly examined, it will be seen that the acid elevator is the only apparatus that can meet the whole of the conditions.

I have purposely omitted any reference to the machines for producing motive power, namely, the air compressors. All the engineering societies contain records of air compressors of various types, and the efficiencies of the standard machines are well known.

In making comparisons as to the cost of raising acids in chemical works and comparing the use of compressed air in acid elevators as against centrifugal pumps, it should be borne in mind that the quantities to be raised are very small compared to the usual pumping problems, so that the improvement in efficiency of 10 to 15% on one or two-horse power is not really an important matter compared with simplicity and reliability.

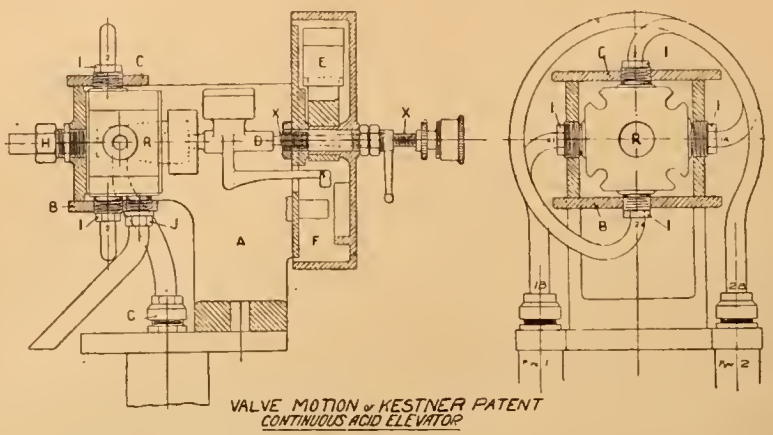


Fig. 6.

The efficiency of a properly-constructed acid elevator in an up-to-date works is from 30 to 40%.

If efficiency is desired beyond other considerations, the Kestner acid pump, as described on page 64 of Mr. West's paper, should be examined.

Discussion.

Captain C. J. Goodwin asked for more information as to the amount of air used and the cost of the operation. He would like to ask, had the author tried using compressed air expansively? When it was required to raise only 15 ft. or 20 ft. and, as was usual, 60 lb. per sq. in. or so was the standard pressure, the air supply was not being used economically. Was it not possible to arrange a device on the elevator to use only part of the air, allowing it to act expansively and so save air? It seemed that in the Kestner elevator there would always be a loss at the finish of the blowing period. He was also interested to know how the acid elevator compared with the air lift in actual practice. His own experience was that air lifts were reliable even though there was a little to give in regard to efficiency.

Mr. Reavell replied that the difficulty in giving the information as to cost would be realised by those dealing with acid works. One could not get the average acid manufacturer to allow tests to be made. The figures in one's own laboratory did not help. The greatest difficulty was experienced in getting manufacturers to erect the piping vertically. If the pipes were put up right they would probably get a very high standard of efficiency with the use of compressed air. When the pipes were erected horizontally there was a loss of air. Regarding the differences of pressure required and available, one started at atmospheric pressure, and when the balance pressure was reached the pressure further increased by about 10%. Because there was 60 lb. air pressure available it did not mean that 60 lb. pressure obtained in the body of the elevator; only sufficient pressure obtained in the body to overcome the head plus friction losses. A reducing valve was not needed, in his opinion. The acid elevator should not be filled slowly but quickly to get quick action. If the elevator valve gear is properly adjusted there is no loss of air.

Captain Goodwin asked if that was why they liked to preheat the air.

Mr. Reavell replied that that was so. With regard to the air lift and the acid elevator, as one of the first to introduce the Bacon air lift from America, his experience was that there was no comparison in efficiency.

Mr. S. J. Tungay said that a difficulty had always been in the fact that the engineering side did not meet with the demands of the chemists. Despite the criticism of the old methods of pumping acid, he thought there was still a great deal to be said for them. He had not adopted the Kestner type or similar types. One reason why he had not adopted such types was that to-day men were not willing to do the work of replacing the various parts. The plumbers objected to coming out specially to a job and insisted that plumbers should be kept on the place at all times.

Mr. Reavell said that so far as the question of splash was concerned they had a simple arrangement which ensured that there was absolutely no waste by splashing. There was no trouble regarding expansion of the delivery pipe when the pipes were put in right.

THE "MARCLEN" GLANDLESS ACID PUMP.

BY R. STEWART.

The Marclen pump possesses certain features in common with other centrifugal pumps, but differs from them in being glandless. Essentially it consists of a casing and a rotor or impeller with a vertical spindle. This is a departure from the usual practice, as, of course, most centrifugal or rotary pumps have horizontal spindles. This method of construction has been adopted in order that glands may be dispensed with, thus obviating the inconvenience of leakage from glands and delay and expense incurred in the frequent renewal of packing in stuffing boxes. Moreover, friction is eliminated, and this in itself is a great advantage, especially in the case of pumps made in regulus, ebonite, or earthenware, intended for dealing with corrosive acid. Fig. 1 exhibits the Marclen pump in one of its more simple forms. The casing is suspended by means of bolts from a strong cast-iron frame resting upon girders lying across the acid tank in which the pump casing is placed, the bolts being covered with lead to prevent contact with the

acid. The vertical spindle, which is also lead-covered up to the underside of the bottom bearing, extends upwards and revolves in two bearings which

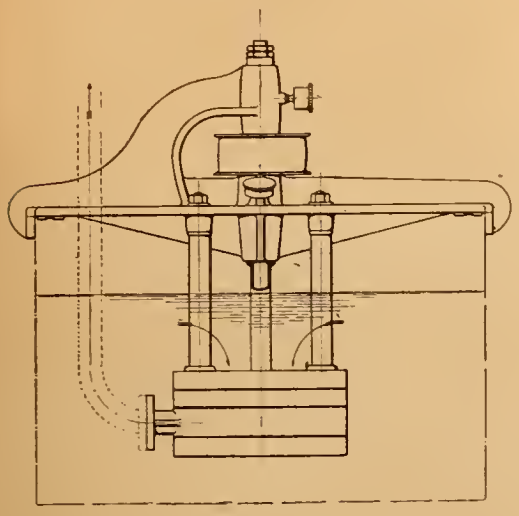


Fig. 1.

are fitted in the cast-iron frame. These two bearings maintain perfect rigidity in the spindle and prevent any tendency to "whip," whilst the thrust-ball bearing at the top and the collar under the upper bearing make any vertical movement impossible.

When the pump is working the acid contained in the tank is drawn in at the vortex which is formed both at the top and the bottom of the casing, and is expelled from the annular duct in the casing upwards into the delivery pipe. The outlet from the casing may be, and sometimes is, tangential.

There is no limit to the size of the tank in which the pump is immersed, but in practice it is sometimes convenient to place the pump in a small tank connected with a larger storage tank, in which case, should the latter be deeper or on a higher level than the pump tank, the supply of acid to the pump is regulated by means of an ordinary valve, or a valve controlled by a float.

Fig. 2 represents a later development of a belt-driven Marclen pump.

The special feature in this design, as well as in the two-stage pump with direct coupled motor (Fig. 3), is the annular float, A, which controls the admission of liquid through the inlet, C, and the annulus, L. It will be seen from the illustrations that the upper sloping part of the float seats itself on the corresponding sloping part of the annular port, which really constitutes a valve seating. The float moves freely in a vertical direction, but is not in contact with the spindle, as it is guided by the small ribs shown as upper extensions of the ribs, M. These ribs, M, of which there are four, form a rest for the float, and guide the liquid steadily into the eye of the impeller, F, which converts it by centrifugal action to pressure in the chamber, G, whence it is forced through the outlet, H, into the delivery pipe. The impeller, F, is mounted on the spindle, D, which revolves in large bearings, K and O, the spaces between the bushes and main casting in each case forming grease reservoirs. The weight

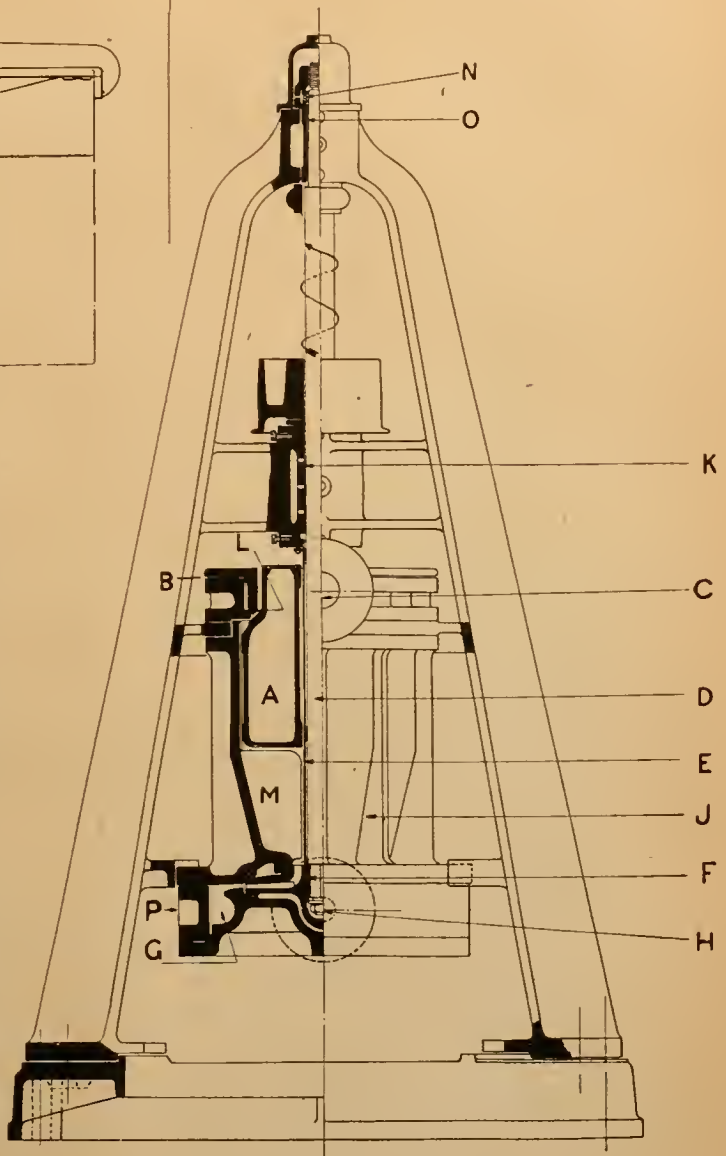


Fig. 2.

of the spindle and impeller is taken by a ball-thrust bearing, N, which revolves in a covered grease chamber. All wearing parts are fitted with automatic grease lubricators. No parts liable to wear are exposed to the action of the acid. The body of the pump, J, the impellers, F and F_1, the sheathing of the spindle, E, the float valve, A, and annular inlet chamber, B, can be made of any suitable acid-resisting metal, stoneware, ebonite, or glass.

When working a full supply of acid is allowed to flow into the inlet, C, and, should this be too much, the float valve, A, rises and temporarily restricts the supply, but falls again when the level of the acid in the pump body becomes lower.

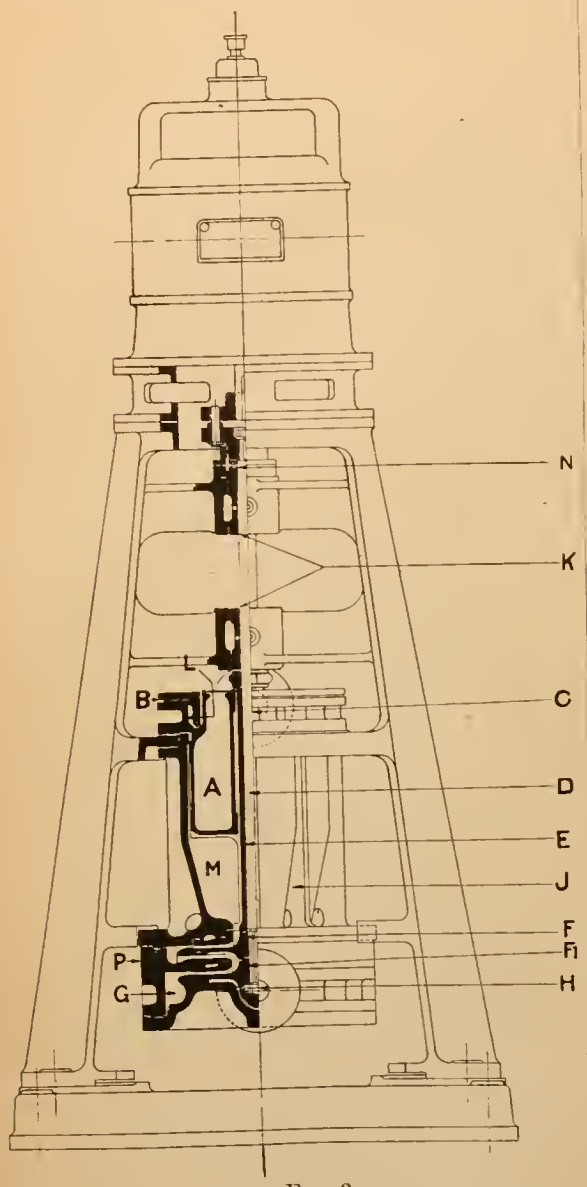


Fig. 3.

The foregoing description applies more particularly to the Marclen pump specially intended for elevating sulphuric acid. But by a comparatively small modification of the design the pump is equally well adapted for raising other acids, such as nitric, hydrochloric, and acetic acids. As a matter of fact, these pumps have been working for over two years with various corrosive liquids, including concentrated and dilute sulphuric and phosphoric acids, and strong hydrochloric acid, also very strongly alkaline liquors at the boiling point, containing a heavy sediment mixed with ashes.

The following are some of the uses, too, for which the Marclen pump is well adapted:—

The elevation of hot saline solutions to crystallising vessels.

The removal of salts deposited from solutions undergoing evaporation.

The emptying of caustic soda or sodium sulphide finishing pots.

Mixing liquids and solids in dissolving tanks; employed for this purpose, either outside or immersed in the dissolver itself, the Marclen pump imparts a vigorous agitation to the contents of a relatively very large vessel.

The Marclen pump is at present made in the following sizes and capacities:—

Type.	Size of openings.		Static head in feet.		Capacity.	B.H.P. (water).		R.P.M.
	Inlet. ins.	Delivery. ins.	1 Stage.	2 Stage.	Galls. per hour.	Single stage.	Two stage.	
A	1½	1½	40	75	800	1·0	1·75	1420
B	1½	1½	40	75	1200	1·25	2·0	1420
C	1½	1½	40	75	1600	1·6	2·5	1420
D	2	1½	40	75	2000	1·8	3·0	1420
E	2	1½	40	75	2300	2·0	3·75	1420
F	2½	2	40	75	2900	2·3	4·0	1420
G	2½	2	40	75	3300	2·5	4·5	1420

Note.—H.P. required varies with the specific gravity and natur of the liquid pumped, particulars of which, together with prices, will be sent on application.

The Marclen pump is manufactured by Marcus Allen and Sons, Ltd., of Elsinore Road, Old Trafford, Manchester.

Discussion.

Mr. Tungay asked whether Mr. Stewart had experienced any difficulty owing to the large diameter of the valve seat which had to be secured at the top end of the float. He had described a certain amount of revolving motion by the float, and it appeared to be one of the weak points. He also thought that Dr. Lunge had described a similar sort of pump suspended vertically in a tank of acid.

Mr. Stewart said that the pump had not yet been made with the particular valve in question, but it was working quite successfully in its original form. He had not seen anything like the Marclen pump, but he would certainly look it up. When the pump had first been made there had been no difficulty in getting a patent.

Mr. Reavell said that it seemed to him that, with the exception of the float, the pump was practically the same type as one already constructed. During the war Mr. Kestner had built a large number of pumps of that type, the difference being in the float. He was rather at a loss to know what the float was for. If it was to relieve the footstep bearing, what was the use of the thrust bearing? If it was not for that reason he did not quite see the object of the float.

Mr. Stewart said the thrust bearing and collar under the bearing was simply to prevent the vertical movement. The office of the float was to deal with a big head of acid which might be so great as to give the pump too much to do. He was unaware that a pump had been made like that. He believed the Rees Roturbo pump was provided with glands. (Mr. Reavell: No.) He was not aware, excepting from what he had heard that night, that there was any pump on the same lines in use in the chemical industry. The whole of the bearings were above the acid.

Mr. H. M. Ridge remarked that he had used something like the same sort of thing before the war for the circulation of weak acids which had certain particular difficulties about them. He had intentionally made the bottom of the rotor flat and achieved excellent results. It was not the same type of float as in the Marclen pump.

Mr. STEWART said that in liquids containing a large amount of sediment one would not have a rotor like that shown in the diagram, but a plain one.

Mr. W. HAYHURST asked whether Mr. Stewart had seen the vertical pumps used by the Ministry at Queensferry. He had seen a large number there about three years ago. They were made differently from the Marelen pump, but the essential features were the same.

Mr. STEWART replied that he had not seen or heard of them.

Capt. GOODWIN said that certain pumps of a similar character had been used in South Africa and America, but they were not exactly the same design. He thought the fact that the patent had been granted was sufficient to get on with the job of making them. Regarding the question of mixing it might be of interest to mention that he had made use of a centrifugal pump for neutralising the contents of a large vat by drawing the liquid from the bottom and distributing it again through perforated pipes immersed in the vat. The neutralising agent was introduced at the pump inlet. He reduced the time for neutralising the contents of the vat to about one quarter of that required by the ordinary stirring gear.

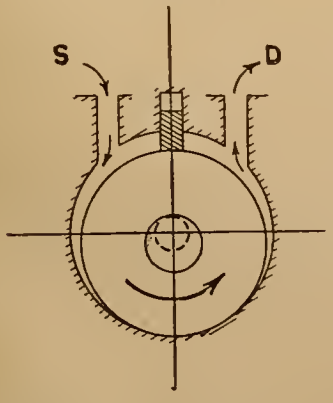
Mr. H. JACKSON said the pump appealed to him as it had no glands. He had a great deal of trouble in pumping sulphuric acid, as the glands were always leaking. He confessed it would be a long time before he would be persuaded to use a centrifugal pump with glands.

Mr. STEWART said he would never be persuaded again to use a pump with glands. One or two of the pumps they had had were much simpler than anything he had described there.

THE AVAMORE "SQUEEGEE" PUMP.

BY R. A. PELMORE.

For very wide and varied conditions on land and sea there has long been required a reliable, high-speed, positive pump of simple construction. The subject of this brief paper is the invention of Mr. N. G. Beckwith, to whom credit it due for an original idea of great utility, and one which cannot fail to be appreciated in our great chemical industries. Most particularly is this the case, owing to the essential simplicity of construction, which is so important for dealing with a wide range of chemicals when it is not always possible to provide metals free from corrosion, and suitable for sound and practical machine construction.



The outstanding requirements for pumping chemicals in addition to the usual desired features of good efficiency and high speed, are (1) reliability, (2) rock-bottom simplicity for rapid overhaul, (3) easily replaceable parts, (4) minimum corrosion and leakage, (5) positive action without priming. Before touching on these questions in detail, the general operation of the pump will be briefly described.

A rotor consisting of a disc loosely mounted on an eccentric on the shaft rolls round the inside of the pump casing. No sliding takes place between casing and rotor, but rolling motion is imparted to the rotor, which turns round the eccentric, the latter acting as a bearing. At the top of the casing a metal piece, usually with some spring tension behind, works up and down in a slot, keeping contact at all times with the rim of the disc. Inlet and outlet ports are immediately to right and to left of this metal piece or valve. "Squeegee" action drives the liquid round in front of the rotor, which, being sealed from the suction side by the valve piece, is driven through the delivery port, while at the same time liquid follows behind the rotor through the suction port. This is the whole action of the pump.

Constructional simplicity.—The pump consists of a casing, end covers, a shaft and two discs with two valve pieces. The discs and valves are duplicated for perfect balance, even flow, and silent running.

Wearing surfaces.—The casing and rotor do not have sliding wear against each other. The sliding surfaces are the main bearing bushes for the shaft and the bore of the rotor disc on the eccentric. It is to be noted that the discs rotate round their own centres at a speed proportional to the difference in diameter of casing and rotor, so that for a pump speed of say 1000 r.p.m. the rim of the disc only makes about 60 complete turns per minute past the valve piece, so making the wear there negligible. This is a very useful feature.

Reliability.—The constructional simplicity and the restriction of principal wearing surfaces to bearings, as well as the absence of valves, without sacrificing the positive action or ability to run without priming, makes a pump of extraordinary reliability.

Replacement of parts.—A glance at the illustrations shows how easy it is to replace rapidly any part without skilled men; the simplicity and therefore cheapness of the moving parts is also shown. The time saved in such rapid replacement may be quite a considerable item to a chemical works.

Corrosion and leakage.—Such a variety of substances may be pumped that it would be futile to enter in detail into the materials used in the vari-

ous instances. The pump in question has been sold for ammoniacal liquor, petrol, tar, creosote, linseed oil, whisky, port wine, milk, brine, sugar molasses, chlorine water. For strong acids and other highly-corrosive liquids it is easily seen that this pump will involve an upkeep in money and, what is usually more important, time, less than any other positive pump known.

Priming and vacuum.—It is most unsatisfactory, in chemical works particularly, to have to prime a pump, and with the "squeegee" priming is eliminated even for suction lifts of 25 feet and over. This property of drawing a good vacuum is a great merit, and one can open and close a cock on the suction pipe leading straight to atmosphere, while the pump picks up immediately, and even with a considerable inflow of air into the suction pipe through leaving such a cock partially open the pump lifts a fair proportion of its normal output. This minimises the effect of leaking suction joints should such leaks develop.

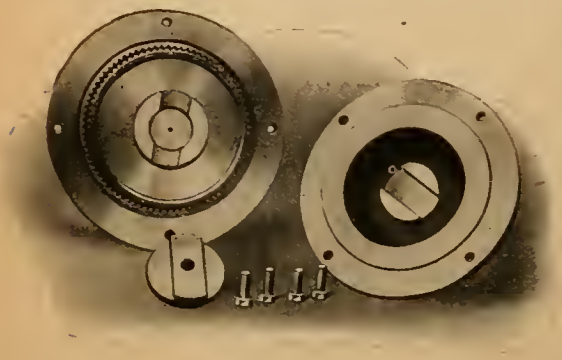
Reversibility.—By the addition of a simple attachment in connection with the pump the delivery and suction connections remain the same for either direction of rotation. Furthermore, the simple standard model when reversed simply changes the delivery pipe into the suction and *vice versâ*, making an admirable arrangement when a liquid is required to be pumped from one reservoir to another and then back again.

Valve action.—No valve, in the usual sense, is used, and it will be noticed that the sliding piece separating suction and delivery has spring tension, but these pumps have been thoroughly tried without springs, and no difference at all has been noticed. The valve piece is held to its work by liquid pressure in the space above the sliding piece, the effective pressure being the difference between the delivery and suction. This is easily demonstrated by removing the plug or lubricator when the pump is running and covering the hole with the thumb.

Balance.—Every pump has a pair of rotors with opposite eccentrics, so that the pump runs noiselessly and smoothly at a high speed.

To sum up, this invention has produced the only high-speed positive pump which has no high-speed wearing surfaces, and these conditions are obtained, together with an excellent suction lift, without priming, these properties being achieved by the simplest design.

"Avamore" reduction gear.—Arising directly from the principle of the pump described is a reduction gear of immense utility. In studying the relative and actual motions of the rotor of the "squeegee" pump, Mr. Beckwith saw that, providing friction was sufficient to keep pure rolling



motion of the rotor round the casing, the principle could be adopted to transmit power with almost any speed reduction desired. An experimental gear was constructed with the casing lined with ferodo, and the principle was found to be practical. However, it was highly desirable to make the gear positive rather than dependent on friction, and the tooth gears were substituted. The gear consists of a casing which houses a ring with internal teeth, while a pinion of smaller diameter is constrained to roll round inside it by being loosely mounted on an eccentric on the shaft. As in the case of the pump, this rotor has a rotational movement relative to its own centre, which is proportional to the difference in effective diameters of ring and pinion. This rotation is transmitted to the low-speed shaft by a sliding member or dog, which slides in a groove in the pinion, and has a second projection at right angles, which slides in a groove in the jaw end of the slow-speed shaft. This gives the equivalent of a universal joint.

The ratio or reduction is $n/(N-n)$, where n = number of teeth in pinion and N = number of teeth in ring. For example, if the ring has 99 teeth and the pinion 96, the reduction is $96 \div 3 = 32$ to 1.

An inspection of the gear shows the compactness and simplicity and brings out the principle of action very clearly. One merit of extreme importance is that a number of teeth are in mesh at the same time, making for smooth and even running, freedom from fracture, and a long life.

The heavy and somewhat clumsy double reduction or even single reduction gears are superseded by this neat and compact design, and few engineers would adopt a worm drive after seeing this gear in operation. A considerable number of these gears have already been in operation in works for some months. By arranging a double reduction in one compact housing a reduction of 400 to 1 has been obtained, and this gear has been at work for some months, although the gear was only invented in the spring of 1919.

Discussion.

Mr. J. A. Reavell said the paper on that type of pump appealed to him, as he had done a certain amount of experimenting on apparatus very largely on the same principle. The trouble had then been a question of lubrication.

Mr. Pelmore said that in the ordinary way the lubrication was ordinary water lubrication. They had had one running six months, and the wear was imperceptible. They had used them for pumping petrol, and although less lubricating than water, it lubricated itself. It ran at 1000 r.p.m., or 1000 galls. per hour. They had run it at 1800, and the water film had been quite sufficient. In sea water they had successfully used a special metal for preventing galvanising action.

Mr. F. R. Lowe asked what was the clearance between the rotor. In dealing with large quantities of liquid in which small bodies might be in suspension pumps would not work on the squeegee principle.

Mr. Pelmore said that they had run the pump on sandy water, and the tests were done without rubbers. He thought the rubber would deal with the sediment. It would not matter if there was a negative clearance.

Mr. Lowe: Then there will be excessive wear.

Mr. Pelmore replied that if one kept on getting a good deal of matter in suspension it might affect the life of the rubber, and all that would mean was that one could get it re-tyred. If constantly dealing with sandy materials it would be wise to provide spare rotors, and if one showed wear after a year or so it could be sent away to be re-rubbered and the spare put on. The fixing of the spare was a very simple operation. They had made careful and special tests to see that the pump would deal with liquids containing sediments.

Mr. F. Cunliffe said that in his experience with rotary pumps, whilst the pump might work well with hot liquids it lost when working with cold liquids, or *vice versâ*.

Mr. Pelmore suggested that in such a case the adjustment should be made to the highest temperature they expected to get. The effect would be a slight diminution on efficiency in running on cold liquor and the maximum on hot. In the case of hot water from a hot well one could work with a negative clearance. As to efficiency, the small pump worked out at 55%, but he believed that efficiency would be increased by a small motor running on high speed. The pressure on the glands affected the power so much that the readings were not within reasonable accuracy to give out the real efficiency. As the pump was increased in size that factor would become almost negligible. As they had only carried out proper tests with small sizes he would rather be in a position of not showing a curve than showing one which might have to be corrected as not quite reliable.

Mr. R. A. Stewart asked whether the pump was adapted to the pumping of gas. There was a great need for rotary machinery for gas such as SO_2, and he did not think there was anything yet suitable. He had seen one in Canada some time ago made by Nash and Co. pumping SO_2 of 10%. If the Squeegee pump would pump chlorine or SO_2 there was a great future for it.

Mr. Pelmore said that he hoped the idea would be developed, but, obviously, for success in that direction lubrication was the key to the situation. Until that problem was scientifically solved he should say the machine was not suitable for gas.

Mr. H. Jackson asked what was the greatest head used in the pump.

Mr. Pelmore replied that he thought 183 ft. was the highest they had used, though they did not confine themselves to that. As it got beyond a certain point there was a certain amount of leakage as in every pump.

The Chairman said he thought that Mr. Pelmore had not given the answer that many required regarding wear. It seemed to him that the remarks made by the speakers with regard to excessive wear in the pump lost sight of the fact that Mr. Pelmore had demonstrated that the actual wearing part—the rotor—only revolved extremely slowly compared with the speed of the shaft, and the wear was really very much reduced.

CENTRIFUGAL PUMPS FOR SULPHURIC AND NITRIC ACIDS.

BY S. J. TUNGAY.

Of all methods of lifting sulphuric acid, perhaps none has received greater attention at the hands of chemical engineers during the last few years than the adaptation of centrifugal pumps for this purpose. This is doubtless accounted for as a result of the difficulties encountered in the case of pumps of other types, mainly through valve troubles, whereas with the centrifugal type of pump there are no valves, and the parts subject to wearing action or friction are very small as compared with plunger type or reciprocating pumps.

It is a well recognised fact also that a small centrifugal pump will deal with very large quantities of liquid, whereas for handling the same quantity of liquid by means of a plunger or piston type of pump a machine of very much larger bulk would be required.

Another decisive factor which induced chemical manufacturers and engineers to regard favourably the improvements in centrifugal acid pumps, is the very high efficiency which can be obtained by this means of lifting acid, as compared with the use of compressed air and acid eggs.

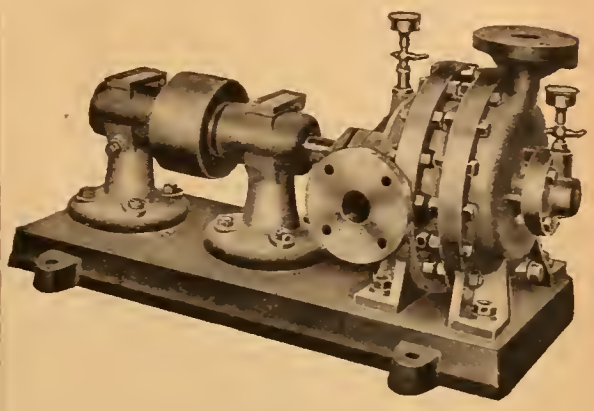


Fig. 1.

In pumping acid by means of plunger type pumps a very great danger always existed from the leakage of acid under pressure from the glands of the pumps. In the more modern types of centrifugal pumps, whether for high or low lifts, this trouble has been avoided by the glands having been so arranged that instead of being subject to pressure of acid, they are only subjected to a suction, and consequently only such packing is needed as will prevent any inlet of air whilst the pump is working.

The Haughton Co. have for some years past greatly improved the design of regulus metal pumps and Ironac metal pumps for the lifting of acids to considerable heights, and for the feeding of Glover and Gas-Lussac towers in sulphuric acid works. Fig. 1 shows one of the more modern types of double-stage regulus centrifugal acid pump for lifting sulphuric acid to a maximum height of 100 ft. From this design it will be seen there is only one gland, and this being on the suction side, there is no fear of leakage of acid at the gland whilst the pump is at work. The pump shaft is fitted with two ring oiling bearings, and is also fitted with ball-thrust bearing so as to take the thrust due to the weight of the head of acid. The incorporation of suitable thrust bearings is a point which many of the earlier designers overlooked when designing pumps for pumping acids to a considerable height, with the result that considerable friction occurred on the pump shaft when working at full speed and heating up of the bearings often resulted. On the pressure side in this pump there is no gland, but simply an enclosed bearing which is maintained full of lubricant from a grease cup. This pump, when lifting sulphuric acid to a head of 75 ft., consumes 1·9 h.-p., and works at 2460 revs. per minute.

A great many pumps of this type have been fitted in this country and abroad at sulphuric acid works and explosive installations during the war with very satisfactory results.

The accompanying table (No. 1) demonstrates the working tests obtained from the working of these multi-stage or turbine pumps when dealing with sulphuric acid of sp. gr. 1·5. By increasing the stages of the multi-stage pumps to 3 or 4 stages it will be seen that a corresponding increase in height of lift is obtained, with, of course, a proportionate increase in consumption of power. In some of the larger sizes of these high-lift acid pumps more elaborate means have been devised to effect a high efficiency in working, and many installations are now working which show as high as 47½ to 55% efficiency.

TABLE No. 1.

Pipe connections		1½			2			3			4	
Average capacity Galls. per min.		27			44			155			220	
Number of stages	2	3	4	2	3	4	2	3	4	2	3	4
R.P.M. .. .. appr.		1380			1280			980			870	
Head in feet	22	32	42	22	32	42	22	32	42	22	32	42
H.P.	0·68	1·02	1·36	1	1·5	2	2·6	3·9	5·2	3·8	5·7	7·6
R.P.M. .. .. appr.		1800			1700			1300			1150	
Head in feet	40	60	80	40	60	80	40	60	80	40	60	80
H.P.	1·1	1·65	2·20	1·70	2·55	3·40	4·8	7·2	9·6	6·6	9·9	13·2
R.P.M. .. .. appr.		2160			2040			1560			1380	
Head in feet	56	84	112	56	84	112	56	84	112	56	84	112
H.P.	1·44	2·16	2·88	2·30	3·45	4·60	6·4	9·6	12·8	9	13·5	18
R.P.M. .. .. appr.		2460			2320			1770			1580	
Head in feet	74	110	146	74	110	146	74	110	146	74	110	146
H.P.	1·90	2·85	3·70	3·1	4·6	6·2	8·8	13·2	17·6	12	18	24

Table 2 shows the capacity, the output, and the power required for this pump when lifting nitric acid at different heads:—

TABLE No. 2.

Ironac Pumps.

Height of lift ..	7ft.	13ft.	20ft.	26ft.	33ft.
Revs. per min. ..	875	1250	1510	1760	1955
Galls. per min. ..	15	20·6	25·4	30	33
H.P. required ..	0·091	0·23	0·375	0·55	0·71
Height of lift ..	40ft.	46ft.	52ft.	59ft.	66ft.
Revs. per min. ..	2160	2320	2480	2630	2770
Galls. per min. ..	36·5	39	42	45	47
H.P. required ..	0·96	1·23	1·54	1·87	2·24
Height of lift ..	7ft.	13ft.	20ft.	26ft.	33ft.
Revs. per min. ..	950	1340	1620	1890	2120
Galls. per min. ..	25·6	36	43	51	57
H.P. required ..	0·19	0·44	0·67	0·95	1·21
Height of lift ..	40ft.	46ft.	52ft.	59ft.	66ft.
Revs. per min. ..	2310	2490	2670	2840	2990
Galls. per min. ..	62	66·5	71	76	80
H.P. required ..	1·63	2·08	2·62	3·21	3·82

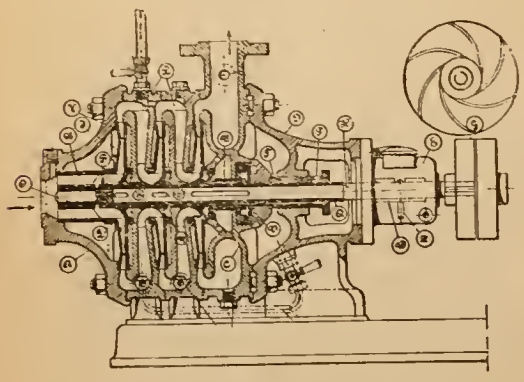


FIG. 2.

Fig. 2 shows a three-stage centrifugal pump again so arranged that there is but one stuffing box and gland, with a thrust collar at the pressure side. This has been arranged with a bye-pass leading to the first or suction chamber so that it is always subject to suction while working, and any leakage or overflow at this point is carried back to the suction side. This forms a very compact and highly efficient design, the impellers being very carefully balanced and internal friction reduced to a minimum.

It must be confessed that many of the difficulties formerly met with in constructing these pumps for dealing with acids have only been overcome as a result of the great improvements during recent years in connection with metals suitable for withstanding corrosion from sulphuric and nitric acids. Internal wearing parts, such as shafts, bearing collars, and liners, can now be made of "Ironac" or acid-resisting iron, whilst the body or casing of pumps is constructed in Regulus or similar metal.

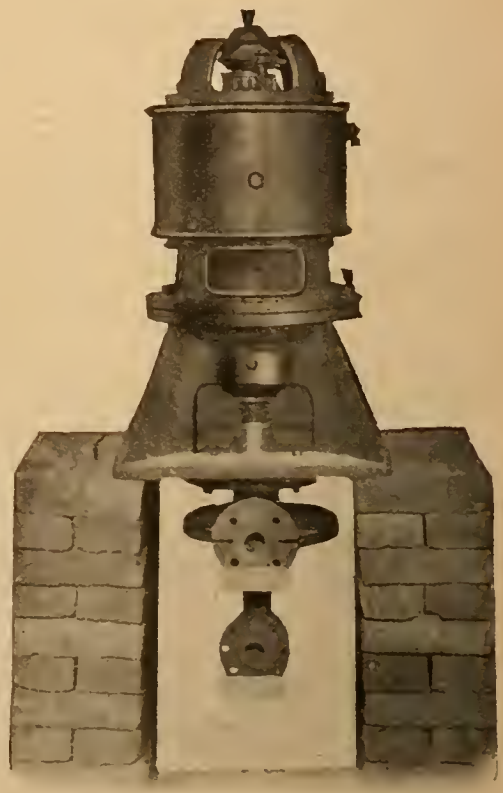


FIG. 3.

Fig. 3 shows a single-stage vertical type centrifugal pump arranged for driving by vertical spindle, motor-coupled direct to pump shaft. This arrangement has much to recommend it, and a number of pumps have been installed fitted up in this manner. The pump chamber has a bottom suction fitted with a balanced impeller, with faced ring on impeller working in machined groove on body in such a way that the gland packing has very little work to do. The ball bearing is arranged on motor spindle, and the pump works with but little internal friction. The multi-stage pumps are often arranged in the same manner.

A centrifugal pump which has been remarkably successful for pumping nitric acid is shown in Fig. 4. This pump is constructed entirely of "Ironac" acid-resisting iron, with the exception of the bedplate, and possesses some rather unusual points. I believe it to be one of the only pumps, apart from earthenware or pottery pumps, in use for nitric acid and nitro bodies. Arranged as shown with an end suction, the impeller and spindle are in one piece. A long stuffing box and sleeve are adopted and oil grooves machined in the spindle and kept filled with ceresine wax lubricant prevent any trouble from leakage at the gland. The spindle is supported by two bearings, each of these being ball bearings and totally enclosed, enabling the pump to be run at comparatively high speeds with a minimum of friction or wear and tear. The use of this pump for nitric acid was early recognised by Mr. K. B. Quinan, who had some of them installed for lifting nitric acid at the Government explosives factories.

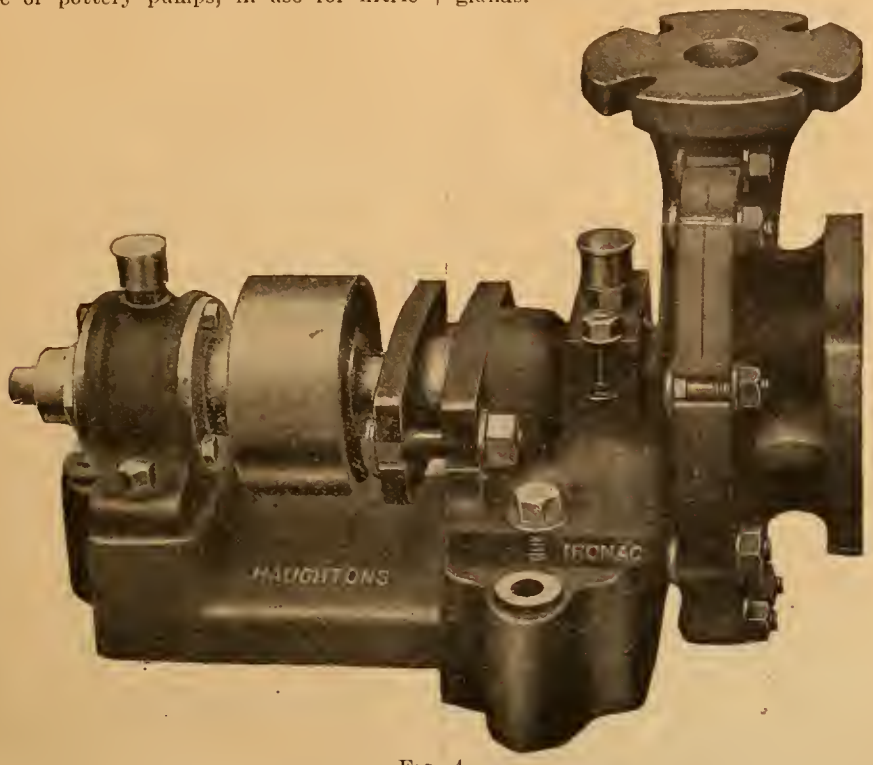


Fig. 4.

Some of these small pumps fitted at the Greetland Factory raised 85% nitric acid to a height of 60 ft. continually at temperatures up to 125° F. Five pumps which were fitted pumped 22,000 tons of nitric acid without any money being spent upon them for maintenance. Truly a record! Although the machine itself is of such small dimensions, these are lifting 240 tons of nitric acid per 24 hours in many works. During the war this pump was very widely installed both in this country and at the munition works of our Allies, where it has earned an excellent record for pumping nitric acid and liquors containing the same.

Discussion.

Mr. H. Jackson asked how the glands stood.

Mr. Tungay said they had many pumps working nitric acid with a head of 85 ft., and they had had no trouble with leakage. With the grooves used the actual pressure reaching the glands was very slight. He found no difficulty with leakage when the pumps were lying idle.

Mr. Jackson said that his experience, though not with that particular pump, was just the reverse. He had always considerable trouble with the glands.

Mr. Tungay said they had made special provision against that. With the old type of pump considerable leakage occurred at the glands, but with the modern plant the glands were not subjected to the same pressure. There was no fear of leakage under modern conditions.

Mr. S. A. Wikner raised the question of pumping "slurries." He remembered having to pump caustic soda in a process of causticisation. He had put it through a small centrifugal pump in which the space between the propeller blades was small and the particles choked it up. It was partially overcome by putting in a straining box. He did not see why the propellers should not always be wide.

Mr. Tungay thought there was no reason why they should not be quite wide and efficieney be attained. He had used the centrifugal pump for copper sulphate and other liquors with crystals and had no difficulty at all. With a considerable clearance he had been able to pump even small stones and gritty water without trouble. He thought that with considerable clearance in the centrifugal pump there was no friction in the internal parts.

Mr. A. Rudge asked whether iron was suitable for the centrifugal pump. He had known the propellers of centrifugal pumps get very brittle and had broken off.

Mr. Tungay replied that if he was referring to cast iron it was a very ambiguous quantity nowadays.

Mr. Reavell remarked that just before the war Mr. Kestner had patented and developed a direct-action pump with a definite clearance, and it was

a perfect success. The leakage was one or two drops per hour. The pump was so successful that the Germans, when occupying Lille, took two truck-loads of them to Germany, as well as the whole of the patterns, and all the detailed drawings.

Mr. TUNGAY said he knew a glandless pump had been doing good work though showing a slight fraction of leakage.

CROW'S IMPROVED METHOD OF TRANSPORTING AND DISTRIBUTING LIQUIDS ABOUT A FACTORY.

BY H. W. CROW.

Though the benefits that result from the use of Crow's improved system of transportation have, in practice, proved to be very great, a quite short description will suffice to explain how it operates.

In the past the transference of liquids to and from the various vessels of a factory or elsewhere has involved more or less complex pipe lines, numerous branches, and a great number of cocks or valves. The branches and the cocks and valves involve a constant liability for the liquid that is being transferred to become contaminated with portions of liquids from other vessels and, conversely, for portions of the main liquid to get into the wrong vessels. This contamination may take place from three causes—the men may leave more than the necessary cocks open; or cocks, correctly shut, may "pass"; and thirdly, liquids from previous operations may be lying in the various branches. These objections are by no means fancy ones. In a naphtha plant, for instance, in transferring high-flash naphtha from a store tank to a filling tank, traces of benzole or other low-flash products have been drawn up through slightly leaking cocks, and thus lowered the flash point of the main product sufficiently to necessitate its rejection. Numerous other incidents of a similar nature have occurred in the writer's works over many years, and it was largely the pressure of these mishaps that led to the development of the present device, a patent for which was granted some little time ago.

The device is a means of putting any given vessel into communication with any other by a kind of switch table, avoiding cocks and valves and branch pipes, either directly or through the intermediary of a pump.

Practical men know that the severest critics of an innovation are the workmen themselves. It is instructive, therefore, to note that our men have heartily welcomed the introduction of the switch table system into the works. The method is immensely simplifying our pumping operations. A further advantage is the very considerable saving in the outlay on cocks and valves.

The essential idea is to bring pipe lines from a number of vessels to one point terminating in such a way as to make a circle of short vertical pipes at the circumference of a table. The end of each short pipe is to be fitted with a cone union. Revolving round the centre of this circle are two radiating arms, one end of each capable of connection to any of the above-mentioned cone unions and the other ends connected to two loops, one above and one below, the further ends of which loops are brought into connection with one another either through two bridge pieces and the suction and delivery of a pump, or through one bridge piece direct. It will be seen that in this way any one of the short vertical pipes of the circumference of the table can be brought into connection with any other and, therefore, any one of the vessels with any other of the group. By making one or more of the short vertical pipes lead to corresponding short vertical pipes of other tables further groups of tanks can be brought into inter-communication. We have a number of tables fixed at Barking, any one of which can be connected to any other by means of these junction lines, either directly or through a third table.

It should be noted that the works pipes that are to be connected to the lower ends of the circumferential pipes must be taken to the bottom of the various vessels to which they lead to allow liquids to be withdrawn or delivered as desired. It is preferable to arrange the tables in a position higher than the highest vessel. If this is not practicable, tiny pet cocks should be fitted at the highest point in the pipes leading to the various vessels in order that siphoning may be prevented.

We would emphasise that the table can be used in conjunction with its own pump or not, according to whether the arriving liquid has to be drawn to the table or whether it is being propelled from elsewhere (by another pump, or by air pressure, or other means). When the pump is not required one of the bridge pieces is swung on one side, and the other connected straight across the two loop terminals. When an operation is completed it is possible, by slowing down the pump, to sweep the pipes all but free from liquid by allowing air to be sucked through.

In working the system we arrange, for the sake of uniformity, that liquids coming to a table travel *via* the lower radiating arm to the lower loop first, then rise *via* the long limb of the upper loop and on through the rest of the upper loop for distribution by the upper radiating arm to the pipe that is to convey the liquid to the receiving vessel. We have provided our tables with little grease cups and brushes so that the threads of the terminal unions may be kept greased. As indicated, the tables are fitted with cone unions, and no trouble arises from leaky joints.

In the rough preliminary model exhibited square elbows were used: in practice the pipes are designed with easy curves. The somewhat tortuous course imposed upon the liquid in no way affects the smooth running of the pumps.

Complete tables will shortly be on the market manufactured under the letters patent No. 130,946, and I hope they will contribute not a little to the efficient transference of liquids in our factories.

Evening Session.

After an informal dinner at the Central Station Hotel the evening session was commenced under the presidency of Prof. P. P. Bedson, of Armstrong College, followed later by Mr. G. Sisson.

Prof. BEDSON welcomed the conference to Newcastle and to the college. Whilst fully appreciating the importance of chemical engineering, chemistry, too, was very important, and he did not want to see one science or branch of the science overshadowing the other. When they came to chemical engineering there was a danger, it appeared to him, that an idea was obtaining that a man could be educated as a chemical engineer between the ages of 17 and 21. A chemical engineer should first be a chemist and then an engineer, so that more time should be devoted to his education than was usually devoted in this country. A man should be first taught to think chemically, then mechanically, then electrically, and then financially. Since he came to college at the age of 17 he wondered when he would leave college. If in three years he succeeded in teaching a man to think and feel chemically he considered he had done well for him.

GENERAL TYPES OF PUMPING MACHINERY FOR CHEMICAL WORKS.

BY J. H. WEST, A.C.G.I., A.M.INST.C.E.

Introduction.

The handling of liquids in chemical works involves problems of the utmost variety, ranging from the lifting of water from deep wells, fire service and boiler feeding, to the handling of highly corrosive liquids and of very thick and viscous liquids. The apparatus available for dealing with these problems presents an equal variety, and the aim of this paper is to collect and tabulate in convenient form for reference a number of types and makers of pumping machinery, which, while obviously not forming a complete survey of all the innumerable makes of pumps now on the market, yet shall be representative of all types.

Information will be given as to the special characteristics of each type and make and their particular spheres of usefulness in chemical works, together with notes on their efficiency where available and other data which may be of use to chemical engineers in dealing with pumping problems.

The paper is divided into four parts, the first dealing with general service pumps, by which is meant pumps for water and non-corrosive chemical liquors; the second part with pumps for gritty liquors, sludges and viscous liquids; the third part with apparatus for handling corrosive liquids; and the last part with pumping by means of compressed air, a section on ejectors being included in this part for convenience.

Pumping problems.

In any pumping problem certain data are required in order to determine the best type and size of pump for the purpose, and pump users would save themselves and the makers much trouble if they would always send full particulars with their enquiries. The information required is as follows:—

1. The quantity of liquid to be pumped in gallons per hour or per minute. If the quantity varies give the maximum, minimum and average.

2. The total dynamic head to be pumped against or, failing this, the total static head, together with full particulars of the size and length of the suction and delivery pipes, if existing, including the number of bends and valves.

3. The suction lift and the variation in head, if any (suction and delivery separately).

4. The nature of the liquid to be pumped, whether clear water, chemical liquor, liquid containing solids in suspension or thick viscous liquid. If other than clear water, the nature and strength of the liquid should be given, and the specific gravity and viscosity.

5. The temperature of the liquid.

6. Whether the pump is to work continuously or intermittently. If the latter give the hours of actual work per week.

7. The nature of the motive power available. If steam, give the gauge pressure at the pump, and the temperature if superheated. If belt drive, give the speed of the shaft and the largest size of pulley that can be provided. If electric give voltage, and if A.C. number of phases and cycles. If compressed air is to be used, and is available, give pressure.

8. In the case of direct-connected pumps it should be stated whether the motor or turbine is to be supplied by the purchaser or the maker.

By dynamic head in (2) is meant the static head, that is, the distance in feet from the surface of the liquid in the vessel or tank from which the pump is drawing to the highest point of the delivery pipe, plus the head required to overcome friction in the pipe including bends and valves.

The friction head depends upon the size of the pipe for a given flow of liquid per minute, and the larger the pipes used the less will be the cost of pumping, but the greater the initial cost of the pipes.

It is a common practice to use larger pipes for the suction than for the discharge, and it is as well to select velocities which give a friction head in the discharge pipe representing not more than 5 % of the length of the pipe line.

Probably the most reliable formulæ for the flow of water through pipes, and the resulting friction head, are those of Mr. A. A. Barnes, which are of the general form:—

$$\text{velocity} = \text{constant} \times m^a . i^b$$

$$\text{friction head} = \text{constant} \times \frac{lv^{a'}}{m^{b'}}$$

where m is the hydraulic mean radius, i the ratio of head absorbed to length of pipe, and l the length of pipe.

From these formulæ the following table of velocities, in feet per second, which correspond to friction heads of 5 % of the length of the pipe, has been calculated.

Pipe diameter in inches.	1	1·5	2	2·5	3	4	5	6
Velocity—								
in uncoated C.I. pipes..	—	3·7	4·4	5·0	5·6	6·6	7·6	8·5
in asphalted C.I. pipes .	—	2·5	3·1	3·7	4·2	5·3	6·3	7·1
in uncoated steel pipes .	2·9	3·8	4·5	5·3	5·9	7·1	8·3	9·3
in asphalted steel pipes.	3·2	4·2	5·0	5·8	6·6	7·8	9·0	10·1
in clean lead pipes ..	2·3	3·0	3·6	4·2	4·8	5·8	6·8	7·7
in clean glass pipes ..	3·1	3·9	4·5	5·1	5·7	6·7	7·6	8·4

The formulæ are given in the Appendix, and it is proposed at a later date to issue separate charts as Data Sheets of the Chemical Engineering Group, showing the friction head at various velocities in these classes of pipes.

The figures given above refer only to clean new pipes, and in selecting the size of pipe for a given flow allowance for corrosion must be made by adding a percentage to the actual flow. In most cases from 5 % to 10 % will be sufficient for this purpose in chemical works, though in water works practice, where the pipes are likely to remain in use for many years, 15 % is often added.

The friction head caused by a standard bend is probably about 0·2 ft., but since the internal smoothness of the pipes after use is a matter of considerable uncertainty, allowance for bends, unless there are very many of them, may be included in that for deterioration.

When liquids other than water are to be pumped, the static head will be that due to a corresponding head of water multiplied by the specific gravity of the liquid, and the friction head will be that due to a corresponding flow of water multiplied by the viscosity of the liquid taking that of water as unity, and having due regard to the temperature at which the liquid is to be pumped, since the viscosity changes greatly with temperature, a difference of 1° F. in some cases producing a change of 5 % in the viscosity.

In the case of very viscous liquids it is often necessary to reduce the viscosity by means of a small steam pipe run through the pipe lines. On account of the greater comparative friction in small pipes the carrying capacity of pipes is not proportional to their area, and a table of pipe equivalents, allowing for this fact, is given in the Appendix.

Selection of pumps.

In selecting a pump for a particular service many factors have to be considered besides first cost, or even efficiency, and as a rule reliability should be the first consideration, because the loss of output due to a breakdown may cost more than the entire

pump. Many people buy pumps entirely on a price basis, the lowest price for any sort of thing resembling a pump which will do the duty given when new gets the order. This is a sure sign that those people do not keep proper works costs, and that they have not the remotest idea what their pumping costs them when it is being done, let alone what it costs them when it is not being done, often a more important item with a low-priced pump.

It is not contended that an expensive pump is necessary for intermittent work; in such cases the interest on capital item may form a big proportion of the total cost of pumping, but in the majority of cases, where fairly continuous service is required, the best pump of its type obtainable is undoubtedly the best investment.

Another point which relates particularly to steam pumps is that it is mistaken economy to work a pump at a maximum rating. It is a common thing in chemical works to see direct-acting pumps slogging away at a speed never intended even by the makers, with the result that they knock themselves to pieces very soon.

Makers usually recommend that pumps for boiler feeding should be worked at half the piston speed given for general service duty, and it is far more economical to use only 70% or 80% of the maximum piston speed for the latter also.

For the same reason a long stroke pump is preferable to a short-stroke one, since the wear on everything except cylinders and buckets, or rams and glands, is dependent on the number of reversals.

The direct-acting steam pump was evolved in order to meet the demand for a cheaper type than the flywheel steam pump, and the duplex pump represents a form of it in which very simple steam valve gear can be used, since the motion of one rod actuates the valve on the other cylinder. These pumps are not economical in steam, owing to the necessity for considerable clearance at the ends of the stroke to allow of cushioning; and the duplex pump, unless particularly well designed, is apt not to work its full stroke on both cylinders, but they are good serviceable pumps if not run too fast.

A ram pump has the advantage over one of the bucket type in that any slip past the plunger is apparent at the stuffing boxes, whereas considerable slip past a bucket plunger may take place without being detected.

The belt-driven centrifugal pump is probably the lowest in first cost of all types of pump, and the efficiency is good for large quantities, but only moderate for medium quantities, especially at high lifts, and distinctly bad for small quantities.

The necessity of priming centrifugal pumps before starting, unless the liquid is supplied from a level higher than the pump, is a disadvantage for chemical work in most cases, but the absence of valves, and the fact that the decrease in efficiency owing to wear is probably less than in the case of reciprocating pumps, especially with the open type impeller, is in their favour.

Trouble at the stuffing boxes is rather frequent in practice, but in many cases this is due to faulty packing, and if a suitable packing for the particular liquor being pumped is selected, there should be no trouble from this source. There is a good deal to be said for the centrifugal pump with only a single stuffing box, and that on the suction side, for chemical work.

In the case of pumps for corrosive liquids the question of safety and reliability far outweighs that of first cost or efficiency, for the quantities to be handled are generally comparatively small.

The choice of suitable valves has much to do with the satisfactory working of pumps lifting chemical liquors, and the provision of efficient strainers of ample area on the suction pipes is of great assistance to the proper operation of the valves.

Pumping efficiency.

Before discussing the comparative efficiency of the various types of pumps, it will be well to have a clear idea of what the cost of power for pumping may amount to in a year.

The number of hours a pump may actually work varies enormously, being only a few hours per week in some cases, while others, such as boiler feed pumps, often work 8000 hours a year.

The following table gives the yearly cost of power for pumping water at various rates against a head of thirty feet, assuming 4000 hours to be worked in the year, and the cost of one b.h.p.hr. to be 1¼d., which is equivalent to electric power delivered to a motor of 85% efficiency at 1·42d. per unit.

Gallons per hour.	Yearly cost of power in pounds at various efficiencies.							
	100%	70%	60%	50%	40%	30%	20%	10%
500	1·6	—	—	—	4·0	5·3	7·9	15·8
1,000	3·2	—	—	6·4	8·0	10·7	16·0	32·0
5,000	16·0	—	26·7	32·0	40	53·0	—	—
20,000	64	91·4	106·7	128	160	213	—	—
50,000	160	229	267	320	400	533	—	—

The second column gives the cost of the power actually necessary at 100% efficiency.

It will seen that the money difference between, say, 40% and 50% is not great with the smaller quantities, and would be quite unimportant with one pump handling these quantities, but where large numbers of small pumps are used the aggregate quantity will be large.

In order to have a basis of comparison between the efficiency of steam pumps and those driven by belt or motor, it is necessary to assume a figure for the steam which represents a horse-power-hour, and in what follows this figure is taken at 35 lb.

The efficiency of pumping by compressed air is dealt with separately in Part IV.

As might be expected, the efficiency of small pumps of all types is very low, owing to the small hydraulic mean radius of the passages, and this is particularly marked with centrifugal pumps.

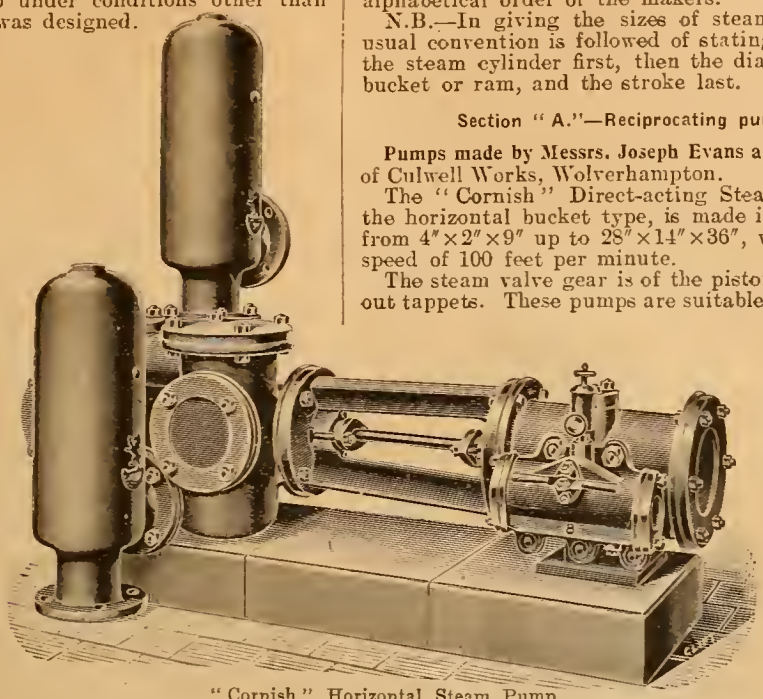
A 1 in. centrifugal pump throwing 1000 gallons per hour against a head of 30 ft. will have an efficiency of 15% to 18%, a 2 in. pump throwing 5000 gallons per hour will show about 40%, a 3 in. pump throwing 10,000 to 12,000 gallons 55% to 60%, while efficiencies of 70% and over are only attainable in pumps of 6 in. or 7 in. and over, handling 50,000 gallons per hour upwards, quantities which are hardly ever met with in chemical works.

In connection with centrifugal pumps it must be remembered that for any given pump there is a certain set of conditions as to speed, quantity, and head, for which the efficiency of that pump will be a maximum, and any deviation from these conditions will mean a decrease in efficiency.

It is desirable therefore, to some extent, to design every centrifugal pump for the particular conditions under which it is to work, in order to get the best results, and this is what the makers do when the selection of a pump is left to them. They do not, of course, design every pump *ab initio*, but they select from their standard patterns the most suitable size of casing and impeller, and select the most efficient speed for the given duty.

Some curves supplied by Messrs. Gwynnes, Ltd., are given in Fig. 39, showing the relation between quantity, speed, head, power, and efficiency. These curves are plotted on a percentage basis, the conditions which give maximum efficiency being shown as 100%, and the efficiencies being shown as percentages of the maximum, which may be anything actually from 12% to 75% according to the size of the pump.

From these curves can be seen the effect of using a centrifugal pump under conditions other than those for which it was designed.



"Cornish" Horizontal Steam Pump.

FIG. 1.

The efficiency of duplex steam pumps will vary from about 20% in small sizes up to 40% in large sizes, corresponding to steam consumptions of 175 lb. per h.p.hr. to 88 lb. That of direct-acting pumps such as Tangyes' "Special" will range from 25% up to 50%. The efficiency of flywheel pumps is usually several per cent. better than that of direct-acting pumps of the same capacity, owing to the smaller clearances in the steam cylinder and the greater ease in working expansively.

The steam consumption can be reduced considerably by compounding the steam cylinders, and also by fitting condensers to the exhaust.

Where the exhaust steam from pumps can be used for heating liquors in chemical works the steam consumption is of little consequence, since nearly 90% of the heat in the live steam is recovered in the exhaust steam.

The efficiency of diaphragm pumps ranges from about 14% in small sizes up to 20% in the largest sizes usually made.

The above figures for pump efficiencies represent average values for pumps by first-class makers and in perfect condition. They may sometimes be exceeded, and no doubt many pumps on the market will fall considerably below them.

PART I.

General service pumps.

Pumps for general service mostly belong to one of the following categories:—

(a) Reciprocating, which include direct-acting steam pumps, flywheel steam pumps, duplex steam pumps, and belt or motor-driven pumps.

(b) Centrifugal pumps, either direct coupled to electric motors or steam turbines, or belt-driven.

The following pumps are described and illustrated as being typical of the best modern practice, and they are arranged for convenience in the alphabetical order of the makers.

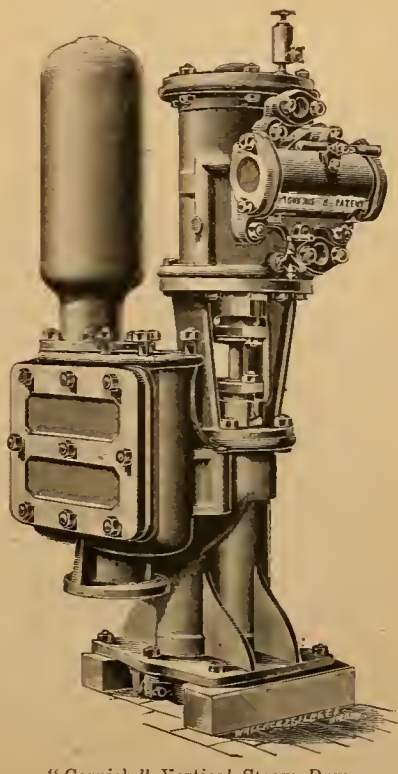
N.B.—In giving the sizes of steam pumps the usual convention is followed of stating the bore of the steam cylinder first, then the diameter of the bucket or ram, and the stroke last.

Section "A."—Reciprocating pumps.

Pumps made by Messrs. Joseph Evans and Sons, Ltd., of Culwell Works, Wolverhampton.

The "Cornish" Direct-acting Steam Pump, of the horizontal bucket type, is made in many sizes from 4″×2″×9″ up to 28″×14″×36″, with a piston speed of 100 feet per minute.

The steam valve gear is of the piston type, without tappets. These pumps are suitable for heads up



"Cornish" Vertical Steam Pump.

FIG. 2.

to 300 ft., and the water ends can also be had brass or gunmetal lined, or all brass.

Some of the sizes can be fitted with long distance pieces for use with chemical liquors, so that no part

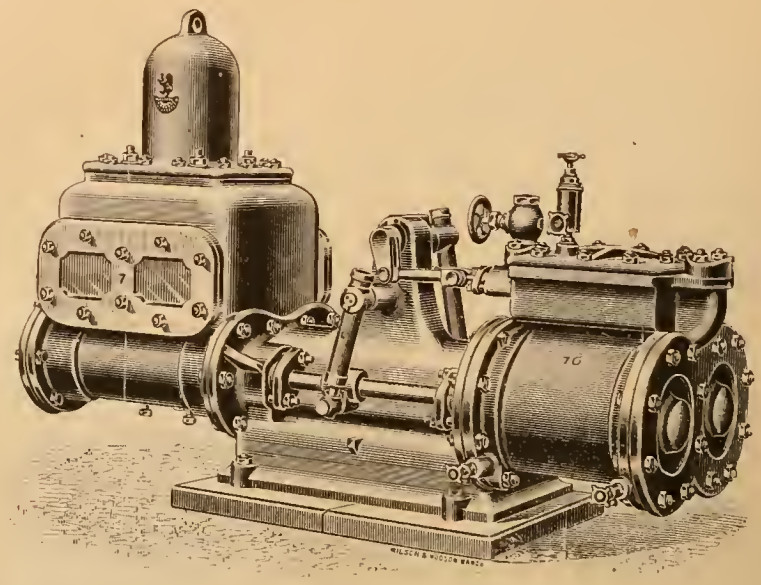
of the rod which comes into contact with the liquor enters the steam cylinder. Fig. 1 illustrates this pump. A similar pump is made of the vertical bucket type from 3″×2″×9″ up to 24″×14″×24″, as shown in Fig. 2.

Duplex pumps, suitable for heads up to 300 ft., and made in various metals to suit different liquors, are made in sizes from $2\frac{1}{2}$″×$1\frac{1}{2}$″×3″ up to 24″×14″×12″. Fig. 3 shows this pump.

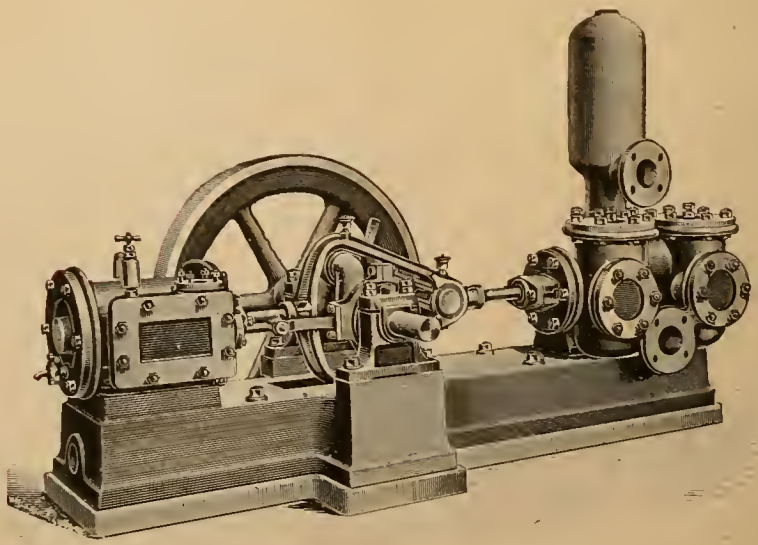
The ram pumps made by Messrs. Evans are described in Part II.

The "Manchester" Pumping Engine is of the vertical flywheel single-acting ram type, as shown in Fig. 5. It is made with one ram from 4″×2″×4″ up to 7″×5″×10″, with two rams from $5\frac{1}{2}$″×3″×6″ up to 16″×11″×16″, and also in a number of sizes compounded.

The "Manchester" Donkey or Wall Pump is of similar type to the above, but arranged for fixing to a wall. It is made from 2″×1″×2″ up to $8\frac{1}{2}$″×6″×8″ with single-acting ram, and from $2\frac{1}{2}$″×$1\frac{1}{4}$″×$2\frac{1}{2}$″ up to 7″×5″×6″ with double-acting bucket.



Duplex Pump by Evans.
FIG. 3.



"Reliable" Flywheel Pump.
FIG. 4.

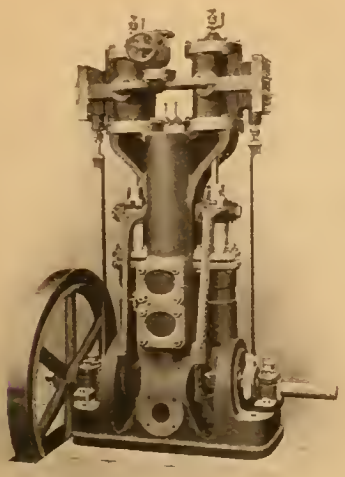
The "Reliable" Pumping Engine is of the horizontal flywheel bucket type, illustrated in Fig. 4. The sizes range from 4″×2″×4″ up to 16″×9″×12″.

Pumps made by Messrs. Frank Pearn and Co., Ltd., of West Gorton, Manchester.

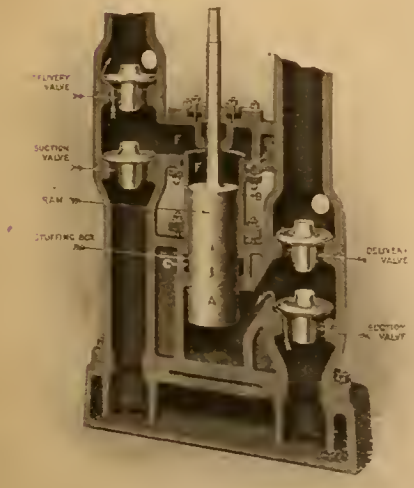
"Cameron" Type Pumps, of the vertical flywheel single-acting ram type, with the columns supporting the steam cylinders used as air vessels, are made in the following sizes:—single ram, from 4″×2″×3″ up to $8\frac{1}{2}$″×6″×8″, and double ram from 4″×2″×3″ up to 18″×15″×15″, the latter type in

two series suitable for pressures up to 100 lb. and 160 lb. per sq. in. respectively. There is also a compound series for the latter pressure from 3″ & 5″×2″×3″ up to 7″ & 12″×6″×8″.

The "Pearn" Pump.—This pump is of similar type to the above, but of improved construction. Fig. 6 shows a section through the double-acting single ram pump, the special feature of which is



"Manchester" Pump by Pearn.
FIG. 5.



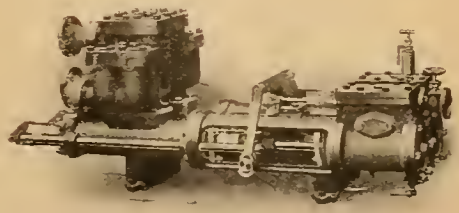
"Pearn" Double-acting Ram Pump, Section.
FIG. 6.

the top pump chamber, which gives the advantages of the double-acting ram type combined with great simplicity and ease of packing, while the steam valve gear allows the steam to be used expansively.

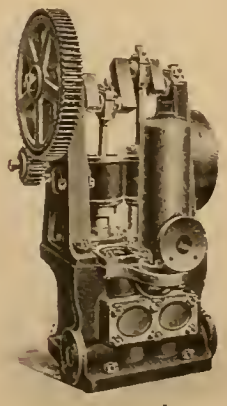
These pumps are made in three series:—Type A for heads up to 60 ft., single ram from 3″×2″×2″ up to 14″×13″×12½″. Type B for heads up to 120 ft., from 3″×1¾″×2″ up to 16″×12″×15″, and Type C for heads up to 200 ft., from 3″×1½″×2″ up to 20″×12″×15″.

A similar pump, but with two rams quadruple-acting, is shown in Fig. 7, and this pump is also made in three series for the same heads as the above, and in about the same range of sizes. Any of these pumps can be had compounded. Type C is suitable for boiler feeding.

"Pearn," Quadruple-acting Pump.
FIG. 7.



Duplex Pump by Pearn.
FIG. 8.

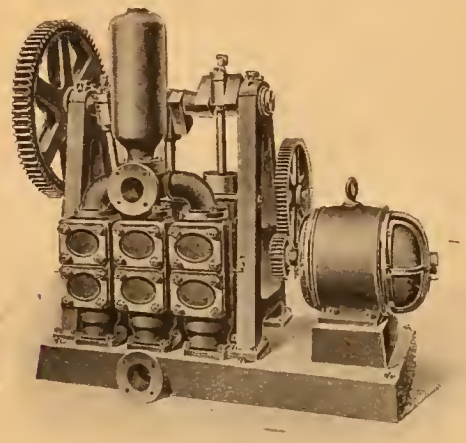


Double Ram Belt-driven Pump by Pearn.
FIG. 9.

The "Pearn" Duplex Ram Pump represents one of the best duplex pumps on the market. It is suitable for heads up to 160 lb. pressure, and is made in a number of sizes from 3″×2″×3″ up to 16″×12″×12″.

A similar pump, but with loose valve boxes, is

also made, and a third series with separate pump barrels and valve boxes, and the rams actuated by outside rods, as shown in Fig. 8, is made from $5\frac{1}{2}'' \times 3'' \times 5''$ up to $16'' \times 12'' \times 12''$. This latter series is specially designed for boiler feeding, and may be had compounded. The "Pearn" Vertical Duplex Ram Pump is made in sizes from $3'' \times 2'' \times 4''$ up to $12'' \times 8'' \times 15''$.

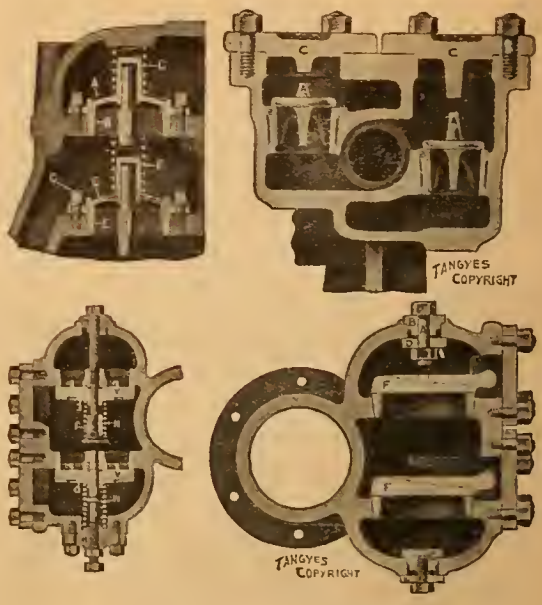


Treble Ram Motor-driven Pump by Pearn.
FIG. 10.

Messrs. Pearn also make a very wide range of power-driven pumps arranged for belt-drive, either direct or through gearing, and also for motor drive through double-reduction gearing.

Pumps made by Messrs. Tangyes, Ltd., of Cornwall Works, Birmingham.

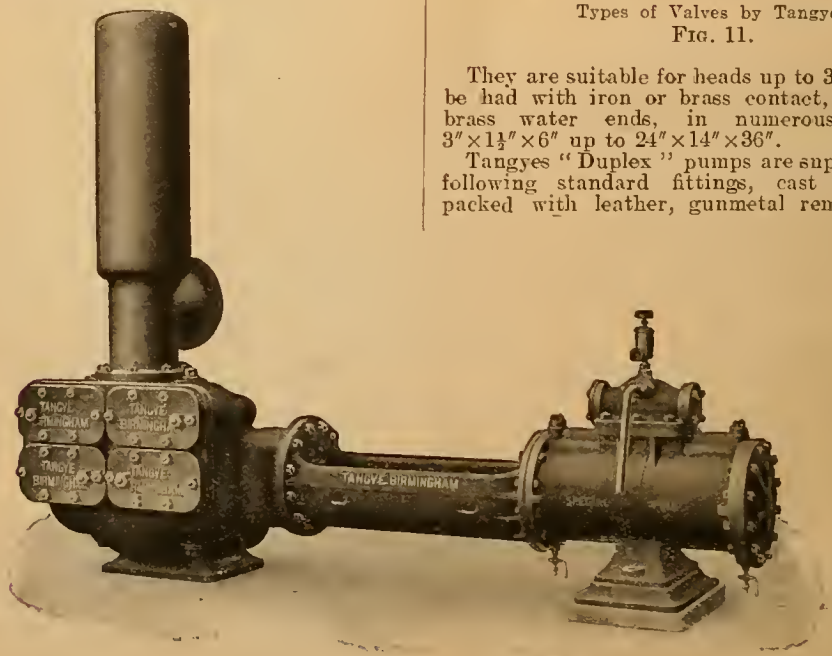
Tangyes' "Special" direct-acting horizontal bucket type pumps are provided with piston valves operated by tappets in the main cylinder. The water valve arrangements are of many different types to suit different conditions, some of them being illustrated in Fig. 11, and the complete pump in Fig. 12.



Types of Valves by Tangyes.
FIG. 11.

They are suitable for heads up to 300 ft. and can be had with iron or brass contact, or with solid brass water ends, in numerous sizes from $3'' \times 1\frac{1}{2}'' \times 6''$ up to $24'' \times 14'' \times 36''$.

Tangyes "Duplex" pumps are supplied with the following standard fittings, cast iron buckets packed with leather, gunmetal removable water cylinder liners, steel rods, gunmetal valves and seats. They can also be had with brass fittings, and with solid brass water ends and Muntz metal rods, and copper or gunmetal air vessel. They are made in a number of sizes from $6'' \times 4'' \times 10''$ up to $20'' \times 14'' \times 10''$.



"Special" Steam Pump by Tangyes.
FIG. 12.

They have from one to three rams, and are chiefly of the single-acting vertical type, though there are also series of horizontal pumps, and one series of quadruple-acting horizontal pumps.

Fig. 9 shows a double ram pump for belt-drive, and Fig. 10 a treble ram pump for motor drive.

The Weir Standard Service Pump, made by Messrs. G. and J. Weir, Ltd., Cathcart, Glasgow.

These pumps, which are of similar type to the well-known Weir vertical feed pumps, represent the highest possible class of workmanship and material in general service pumps. The water cylinder is gunmetal lined, or can be had in solid gunmetal. The pump rod is of manganese bronze. The valves and seats of the group type are of gunmetal. These pumps are suitable for heads up to 208 ft. and steam pressures up to 200 lb. per sq. in. The sizes range from $4\frac{1}{2}'' \times 5'' \times 12''$ up to $12\frac{1}{2}'' \times 14'' \times 24''$.

Section "B."—Centrifugal pumps.

Messrs. Escher Wyss, of Zürich, make several series of very high-grade Turbo-pumps with impellers and guide vanes of special bronze. The double-flow, single stage type is suitable for heads of from 65 to 135 ft. and the smallest size is $3\frac{1}{2}''$ with a duty of 6000 to 12,000 gallons per hour, with speeds from 2350 to 3800 r.p.m. and efficiency of 56% to 60%. The efficiency in the 6-in. size is 67% to 70% and the maximum head 165 ft. The single-flow single stage type is suitable for heads of 65 to 135 ft., and the smallest size is $2\frac{3}{4}''$ with a duty of 3600 to 6000 gallons per hour, and efficiency of 54% to 57%.

The multi-stage, single flow type is made with 2 to 8 stages and $2\frac{3}{4}''$ is the smallest size, with duties varying from 1200 to 4800 gallons per hour.

Gwynnes' "Invincible" Centrifugal Pumps, made by Messrs. Gwynnes, Ltd., Hammersmith Iron Works, London, W. 6.

The standard fittings of these pumps are cast iron casings and impellers, and steel shafts, but they can also be made in brass or gunmetal. The casings are attached to the bed-plate in such a way that they can be swivelled to any angle in a vertical plane to suit the pipe connections. The pumps are made for direct coupling or belt-drive. When required they can be fitted with independent external ring oiling bearings.

The low-lift type, suitable for heads of from 10 ft. to 90 ft., is made in sizes ranging from $\frac{3}{4}''$ upwards, the duty of the smallest size being 600 gallons per hour.

The medium lift type is suitable for heads of from 30 ft. to 90 ft., and is made in sizes of 2" upwards. The efficiency of this type is rather better than that of the low-lift type.

Multi-stage pumps are also made in various types.

Messrs. Mather and Platt, Ltd., of Park Works, Manchester, make an excellent range of centrifugal and turbine pumps from 2" upwards, but they do not make pumps for gritty liquors. **Messrs. Ruston and Hornsby, Ltd.,** of 46, Queen Victoria Street, London, E.C. 4, also make a good range of centrifugal pumps from 3" upwards.

The "Sirius" Centrifugal Pump, made by Messrs. Holden and Brooke, Ltd., Sirius Works, West Gorton, Manchester.

These pumps are made of the single stage and two stage types for direct coupling or belt drive. The casings are of cast iron with gunmetal impellers up to 5", and cast iron in larger sizes. The smallest size single stage is 1" with a duty of 300 to 1200 gallons per hour, for heads of from 20 ft. to 50 ft. The two stage is made in sizes from $1\frac{1}{4}''$ upwards for heads of from 40 ft. to 100 ft. The suction inlet is arranged axially.

PART II.

Section "A."—Pumps for gritty liquids.

Subsection 1.—Reciprocating pumps.

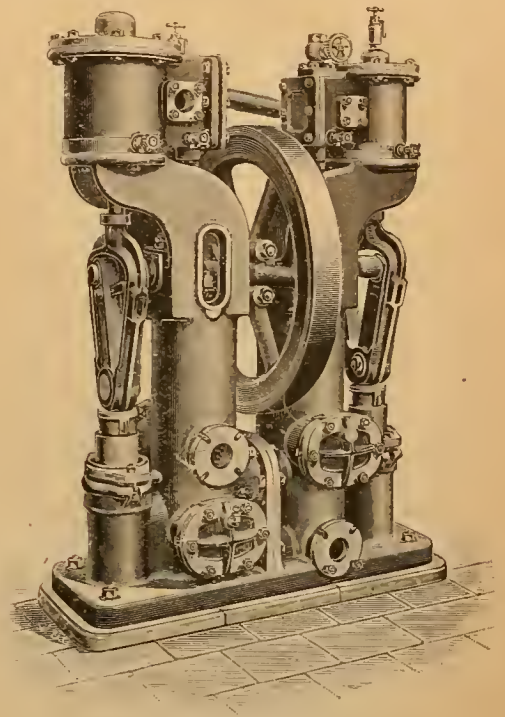
The most suitable reciprocating pumps, other than diaphragm, for handling gritty liquids are those of the outside packed ram type, since in these the plunger does not touch the cylinder and only rubs against the soft packing in the stuffing boxes.

Messrs. Joseph Evans and Sons, Ltd., of Culwell Works, Wolverhampton, supply their "Cornish" pump in the outside packed, horizontal, double-acting ram type in sizes from $5'' \times 3'' \times 12''$ up to $10'' \times 8'' \times 12''$. They are suitable for heads up to 300 ft. and can, if required, be fitted with gunmetal cased rams and gunmetal glands.

This firm also make outside packed ram double-acting duplex pumps in sizes from $6'' \times 3'' \times 12''$ up to $24'' \times 14'' \times 12''$. Gunmetal or brass fittings can be supplied. Some of the larger sizes can also be supplied with the steam cylinders compounded.

The "Reliable" pump, horizontal type, with crank and flywheel, and outside packed rams, is made in sizes from $5'' \times 3'' \times 6''$ up to $24'' \times 14'' \times 24''$. This is a strong pump suitable for high lifts. The water end can be had gunmetal cased.

Messrs. Evans' "Ram" pump, of the vertical single-acting type with crank and flywheel is a favourite in chemical works. It is made in sizes from $4'' \times 2'' \times 4''$ up to $16'' \times 14'' \times 10''$. Most of the sizes are also suitable for boiler feeding.



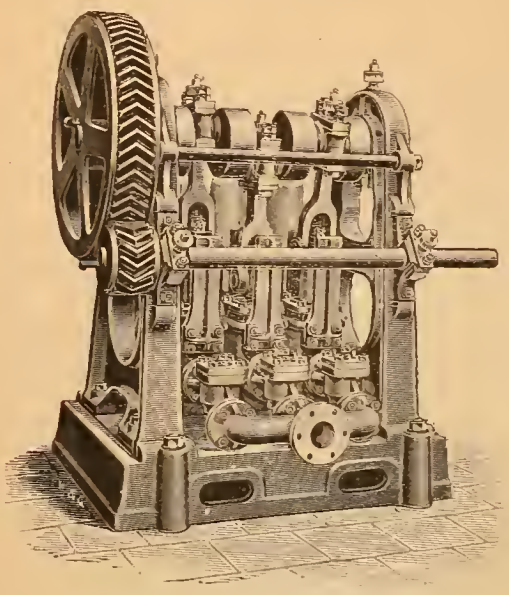
Compound Ram Pump by Evans.
FIG. 13.

A similar type, but with two cylinders with the flywheel between them is made in sizes from $4'' \times 2'' \times 4''$ up to $24'' \times 18'' \times 12''$, and it can also be had with steam cylinders compounded. Fig. 13 shows the arrangement of this pump. Messrs. Evans also make a vertical treble-ram pump in two sizes suitable for heads up to 300 ft. and 600 ft. respectively and fitted with either single or double reduction for belt drive or direct coupling. The sizes range from $3'' \times 6''$ up to $10'' \times 12''$, and Fig. 14 shows the general arrangement.

A very similar pump, treble ram, but horizontal, is made in sizes from $3'' \times 9''$ up to $9'' \times 12''$.

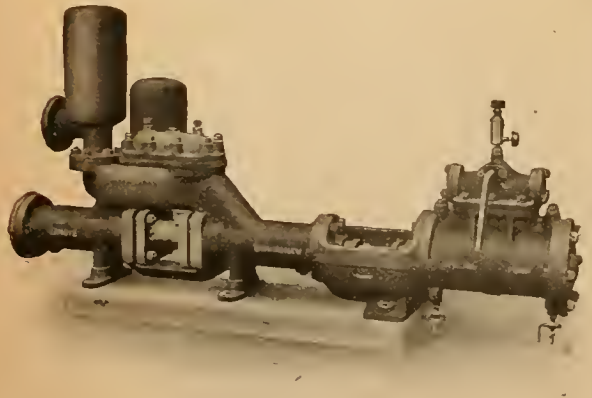
Tangyes' outside packed ram pumps, made by Messrs. Tangyes, Ltd., of Cornwall Works, Birmingham.

The "Special" direct acting horizontal pump is suitable for heads up to 450 ft. and steam pressures up to 100 lbs. per sq. in. The ram may be of iron or brass, and the rod of steel or Muntz metal and the water end of iron or brass. It is made in sizes from 6″×3″×12″ up to 14″×6″×12″.



Treble Ram Power Pump by Evans.
FIG. 14.

The "Special Centre-packed type" is a similar pump but of extra strong construction for heads up to 600 ft., and the valve boxes are outside, as shown in Fig. 15. It can be obtained in the same materials as the above pump and in sizes from 12″×7″×24″ up to 30″×12″×24″.



Mine Type Ram Pump by Tangyes.
FIG. 15.

The "Duplex Mine Pump" is similar to the above at the water end, but with two cylinders working on the duplex system. The sizes range from 18″×7″×15″ to 26″×12″×18″.

Most of the above pumps can be fitted with condensers, and have the steam cylinders compounded in the case of the duplex type.

Tangyes Duplex Ballast Pump is a lighter type suitable for heads up to 80 ft. The standard fittings are gunmetal buckets with gunmetal rings, Muntz metal rods, gunmetal water cylinder liners, indiarubber valves on gunmetal seats with brass springs. They can also be had with brass valves, or all brass water ends. The sizes range from 4½″×3¾″×4″ up to 10″×10″×10″.

Any of the Tangye pumps can be had with extra long distance for dealing with chemical liquors.

The Premier Diaphragm Pump, made for the Premier Filter Press Co., Ltd., of Finsbury Pavement House, London, E.C. 2.

These pumps, which are of the vertical type, belt driven through spur reduction gear, are particularly suited for handling gritty liquors. Fig. 16 shows a section through the pump. The plunger works in water and the diaphragm is made of rubber from ⅜″ to ½″ thick, and rubber-coated ball valves are provided.

Fig. 17 illustrates a two-throw pump, and shows the sound engineering character of the design.

The valve boxes are easily accessible, air vessels are provided, and also a relief valve with sliding weight on the delivery pipe. This is very useful when using the pump for filling filter presses, as the filling pressure can be adjusted to suit requirements and the pump can be run at constant speed, the surplus liquor not taken by the press being returned to the suction tank through the relief valves.

These pumps are made in five sizes, single-throw type ranging from 280 to 1035 gallons per hour; in two sizes two-throw type, giving roughly 2000 to 3000 gallons per hour respectively; and in three sizes three-throw, giving slightly larger duties. There is also a small hand-power type giving 38 gallons per hour.

These pumps are not suitable for liquors at temperatures above 55° C., on account of the rubber diaphragm.

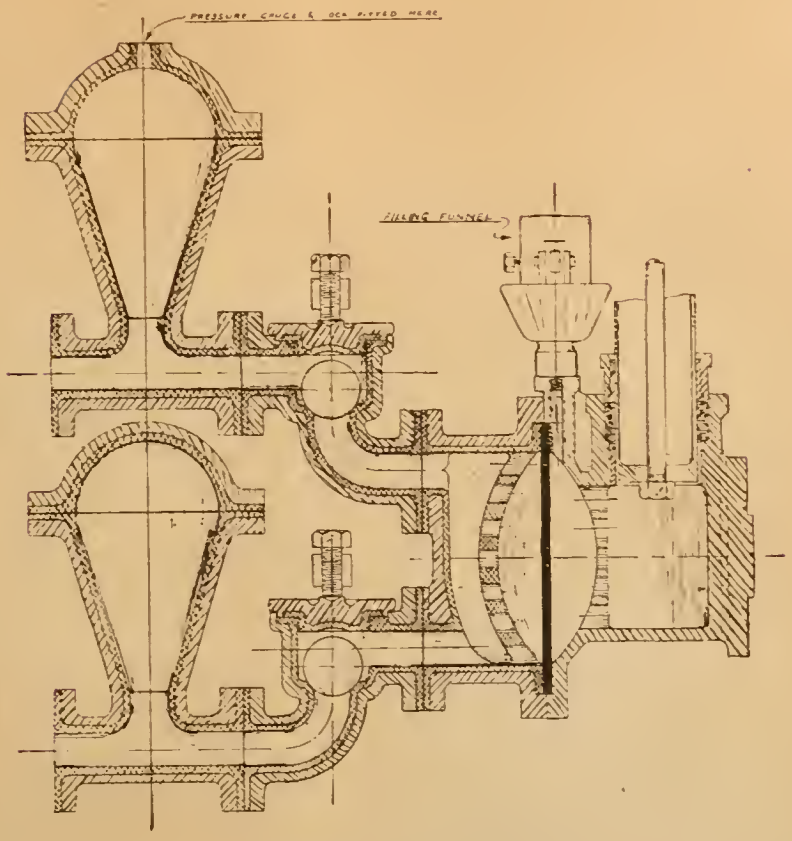
Subsection 2.—Rotary pumps.

Messrs. Gwynnes, Ltd., of Hammersmith Iron Works, London, W. 6, make a special feature of centrifugal pumps for dealing with liquids containing solids in suspension, from fine slimes and paper pulp liquors up to liquors containing large pieces of solid.

An open type of impeller is used, such as that shown in Fig. 18, which has two advantages for this class of work. First, the blades of the impeller have a shearing action and cut their way through the solids, automatically clearing away any obstructions, and, second, there is no narrow joint surface between the impeller and the casing near the hub such as exists in pumps with the enclosed impeller, and upon the tightness of which the freedom of leakage between the delivery and suction sides depends. The open impeller has a very small clearance from the casing all over the sides, and, in the case of pumps for gritty liquors, the interior of the casing is lined with easily renewable wearing pieces, made of a softer material than the impeller, so that the wear comes chiefly on these pieces and not on the impeller, which is made of chilled cast iron or of cast steel. Fig. 19 illustrates a gritty water type pump.

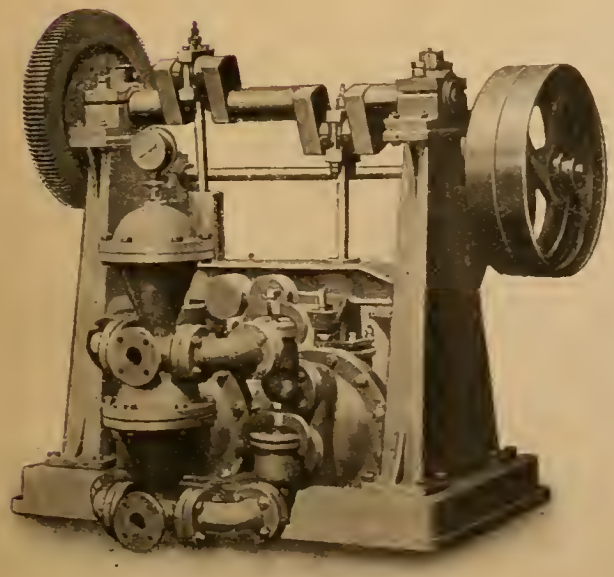
Messrs. Gwynnes claim that the efficiency of these open impellers is fully equal to that of the closed type as far as pumping clear liquid is concerned, but naturally the grinding action of the solids in gritty liquids introduces a certain amount of extra friction.

This firm's Gravel type pump is really a wonderful pump, for it will pass any piece of solid which can enter the suction pipe. For instance, a 4″ pump will pass stones 3½″×6″ long. To attain this result the arms of the impeller are few in number, generally 4, and unconnected by a central web except near the centre. The suction is axial, so that the solids come against the impeller without shock. The



Premier Diaphragm Pump, Section.

FIG. 16.

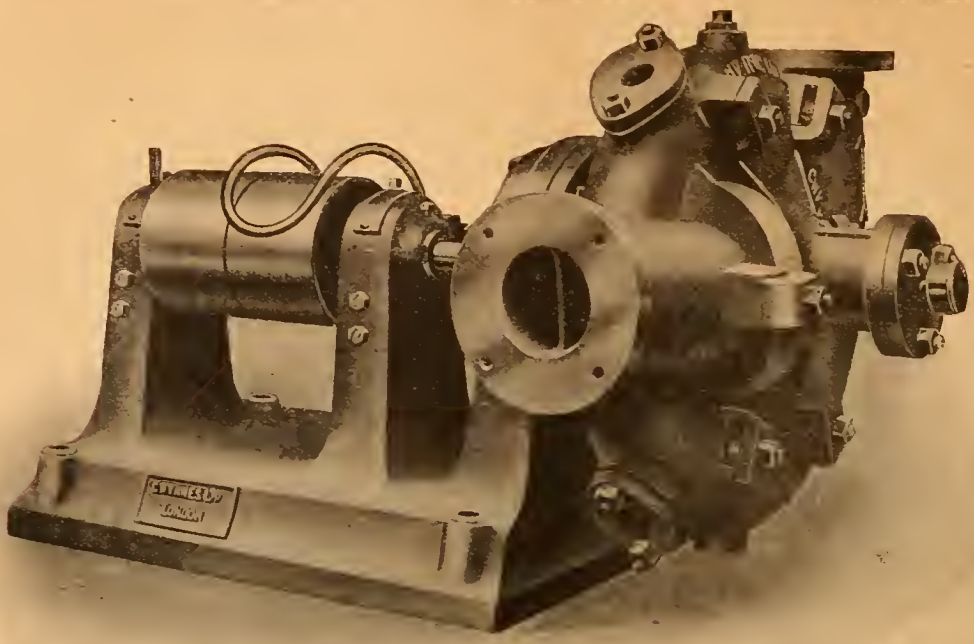


Premier Two-throw Pump.

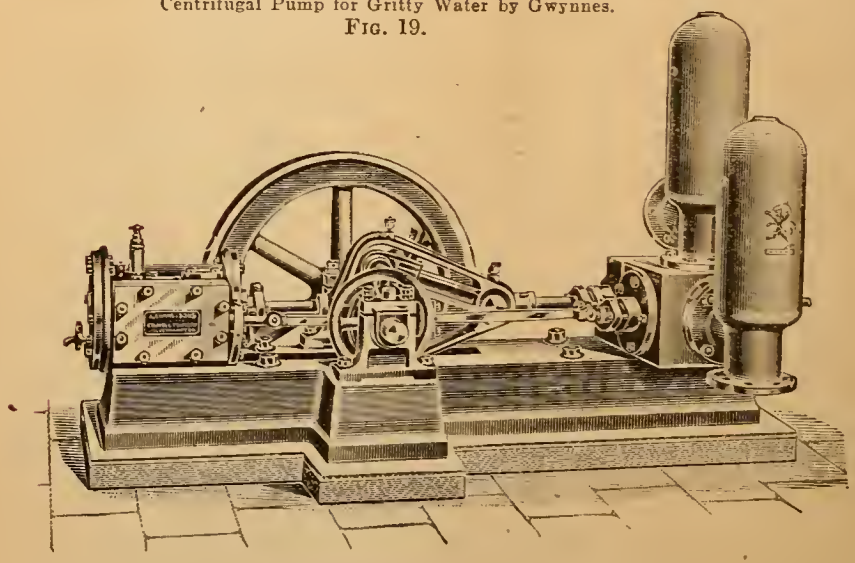
FIG. 17.

Open Type Impeller, by Gwynnes.

FIG. 18.



Centrifugal Pump for Gritty Water by Gwynnes.
FIG. 19.



"Reliable" Pump for Thick Liquids by Evans.
FIG. 20.

whole of the casing is lined with renewable plates. These various types of pumps can be obtained in sizes down to 2".

The "Squeegee" Pump, fully described in another paper in this volume, is very suitable for dealing with gritty liquids.

The Frenier Pump, though not much used in this country, should be mentioned as being very suitable for dealing with sludges. It is of the spiral scoop-wheel type.

Section "B"—Pumps for thick viscous liquids.

The chief difficulty in the pumping of viscous liquids, greases and so forth, lies in the operation of the pump valves, which should be mechanically opened and closed, and not dependent upon springs or pressure of the liquid.

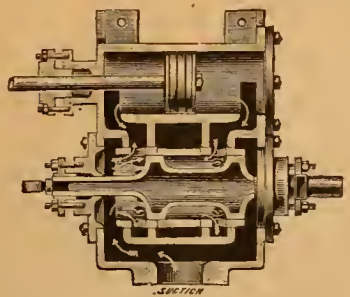
Messrs. Joseph Evans and Sons, Ltd., of Wolverhampton, make a special "Reliable" reversible pump of the horizontal bucket type, with crank and flywheel. Fig. 20 illustrates this pump, which is made in sizes from 4" × 2" × 4" up to 16" × 8" × 12", steam driven, and also arranged for belt-drive.

The steam valve is the ordinary slide valve worked from an eccentric on the crank shaft.

The liquor valve is a single piston valve also operated mechanically by an eccentric, as shown in Fig. 21, and is suitable for use with cold tar,

treacle, varnish, glue, etc. Air vessels are provided on both suction and delivery. Copper air vessels and gunmetal working parts can also be supplied.

The "Drum Pump," made by the Drum Engineering Co., Ltd., of 28, Humboldt Street, Bradford, is of the rotary piston type. Fig. 22 shows a section through the pump, the lower rotating member being the piston, and the upper slotted drum acting as a valve. This pump is suitable for any non-corrosive liquid, and particularly for oils, jellies, varnishes and other semi-fluids, and it is



"Reliable," Section of Piston Valve.
FIG. 21.

Drum Positive Rotary Pump, Section.
FIG. 22.

made in seven sizes from 650 to 24,000 gallons per hour, either for belt-drive or direct coupling. Fig. 23 shows a motor-driven pump.

The "Squeegee" Pump, made by the Avamore Engineering Co., of 179, Queen Victoria Street, E.C. 4, and fully described elsewhere in this volume, is also suitable for thick liquids. It can be made in any metal and is obtainable in the following sizes:—

Size.	Normal speed.	Total head in feet.	Capacity. Galls. per hour.
In.			
¾	1250	100	350
1	1250	100	700
1¼	1000	100	1000
1½	1000	100	2000
2	950	120	4500
3	950	120	9000
4	720	150	13,000

The Douglas Positive Rotary Pump can be used successfully for thick liquids, but since the principal application of this pump is for acid work it will be described under Part III.

PART III.

Apparatus for pumping corrosive acids.

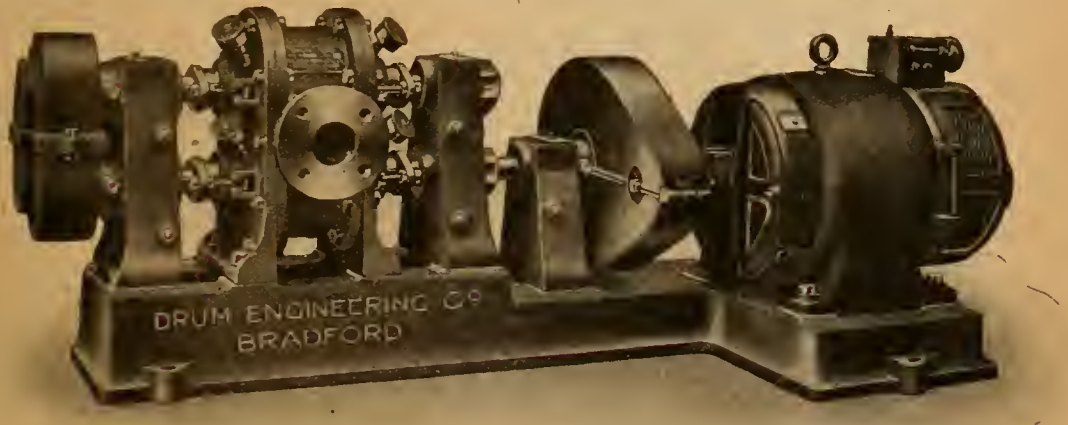
Section "A."—Reciprocating pumps.

Bailey's Regulus Metal Acid Pumps, single acting vertical ram type, made by W. H. Bailey and Co., Albion Works, Salford, Manchester. One form of this pump, which is shown in Fig. 24, is mounted on a standard, with steam cylinder, crank and flywheel, and is made in the following sizes:—

Stroke.	Steam cyl.	Liquor cyl.	
9 In.	5 6	3.3½.4 6.8	P.S.—37½

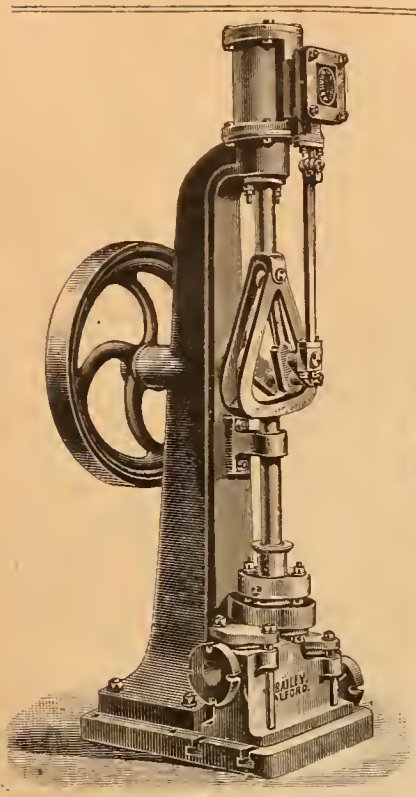
This type is also arranged on a standard for belt driving with 36" flywheel in the same sizes.

A similar pump but arranged for bolting to a wall is made in the following sizes, both with steam cylinder and flywheel and for belt drive.

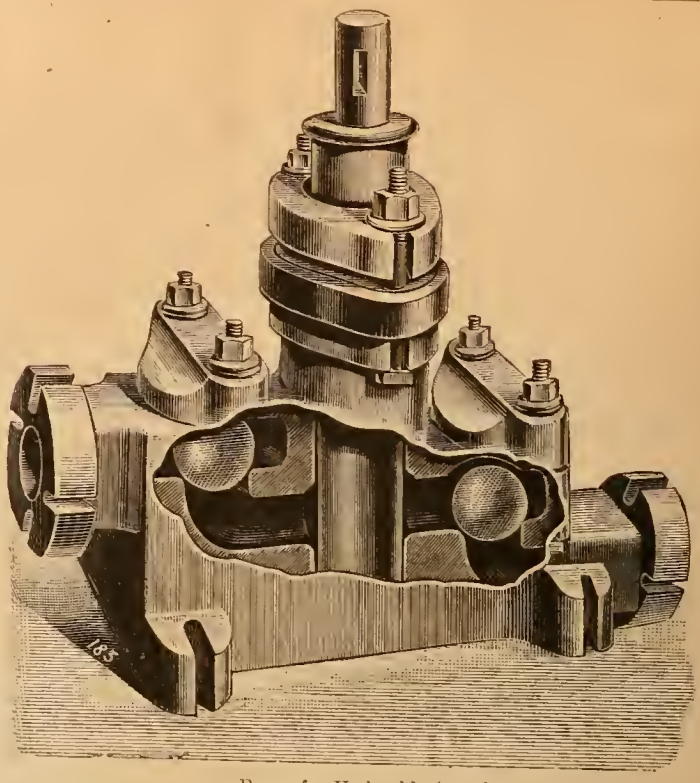


Drum Positive Motor-driven Pump.
FIG. 23.

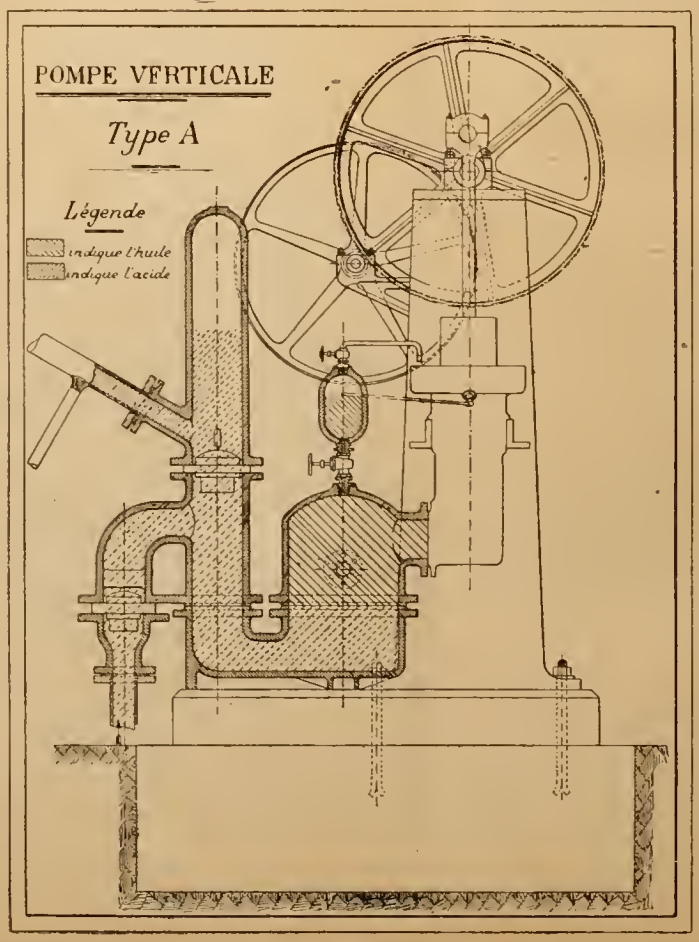
Stroke.	Steam cyl.	Liquor cyl.	
3 4½	2½ 4	1¼ 2.3.4	P.S.—37½



Regulus Metal Pump by Bailey.
FIG. 24.



Pump for Hydrochloric Acid by Bailey.
FIG. 25.



The Ferraris Pump, Section
FIG. 26.

A similar pump, but made of special white metal, for hydrochloric acid is obtainable mounted on a standard with crank, flywheel and steam cylinder, or for belt drive, in the following sizes:—

Stroke.	Steam cyl.	Liquor cyl.	
9	5	3.3½.4	P.S.—22½

Fig. 25 shows the construction of this pump.

Doulton's Stoneware Ram Pump, made by Messrs. Doulton and Co., Lambeth Pottery, London, S.E. 1. This pump is supplied mounted on a framework with crank, spur reduction gear, and fast and loose pulleys. The ram is 4″, the stroke 12″, the P.S. 40, and the pump is suitable for heads up to 30 ft.

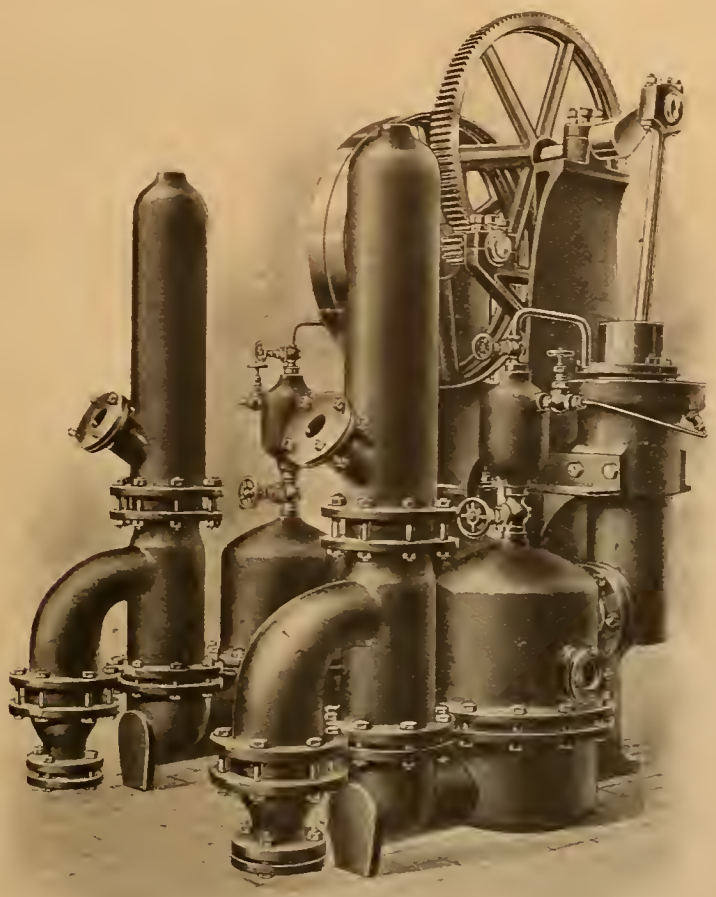
The Ferraris Acid Pump.—This pump, which is of Italian origin, is of the vertical plunger, diaphragm type, but instead of using a diaphragm of rubber a column of oil is used to transmit motion from the plunger to the acid.

Fig. 26 shows the arrangement in section. The parts in contact with the acid are usually made of regulus metal, but they can equally well be made of any other material suitable for this construction.

The pump works at 9 strokes per min., and delivers 6 tons of acid per hour, with a consumption of 1 h.p. when lifting 33 ft., this representing an efficiency of about 22%. Another type is being developed which will handle 8 tons of acid per hour. Fig. 27 shows a general view of the pump.

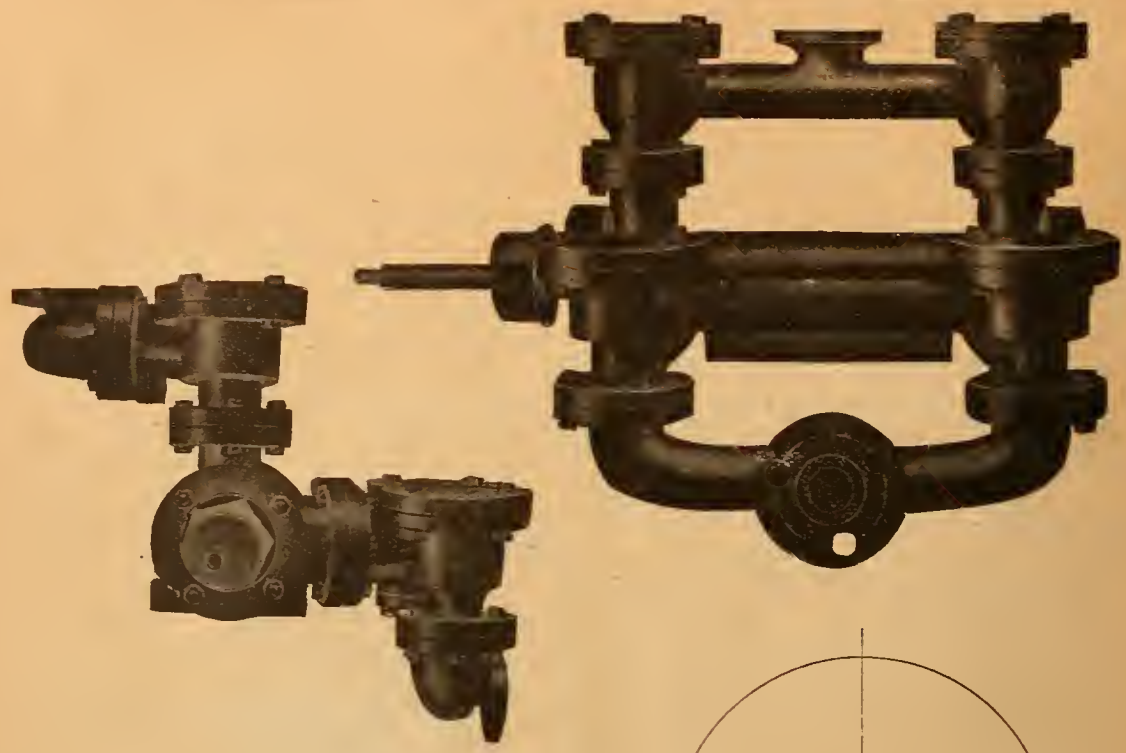
The oil used is a heavy mineral oil, and the only limitation of this pump's sphere of usefulness lies in finding suitable oils to resist the action of various acids. So far it has been used chiefly for sulphuric and hydrofluoric acids, and it is not suitable for nitric acid.

These pumps are very largely used in Italy, one firm having 140 in use, another 52, another 20, and so on; and they have also found considerable favour in France, and to some extent in this country. Several Italian firms state that they have had them in constant use for five years without changing the oil or having to effect any repair.



The Ferraris Pump, General View.
FIG. 27.

The India Rubber, Gutta Percha and Telegraph Works Co., Ltd., of 100-102, Cannon Street, London, E.C. 4, make ebonite pumps of both bucket and ram types, including single-acting vertical and double-acting horizontal series. Fig. 28 shows the front and end views of one of the double-acting pumps. The sizes made range from 2″×6″ up to 6″×10″, with a speed of 25 to 30



Ebonite Double-acting Pump.
FIG. 28.

strokes per min. The valves are of either the wing type or the ball type. These pumps are suitable for heads up to 200 ft., and they can be supplied with rod only for coupling to the user's pump gear, or complete for belt-drive, steam-drive, or motor.

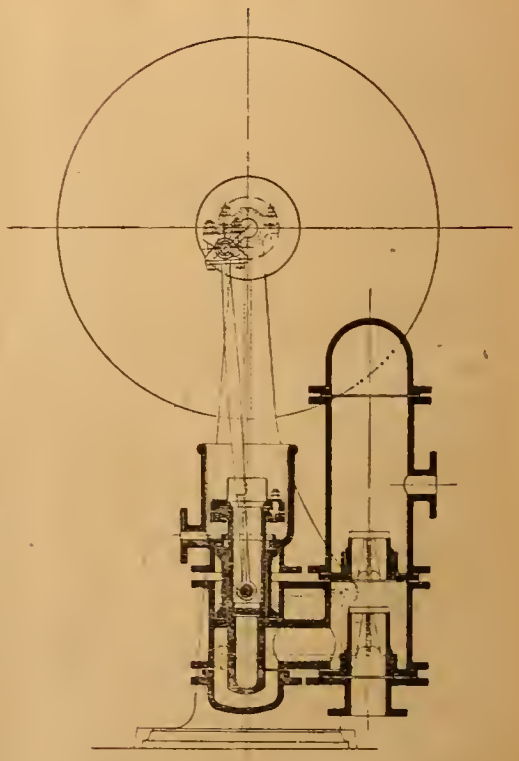
Larger sizes made in cast iron, ebonite covered, can be made to order.

The "Kestner" Acid Pump.—This most interesting pump, which will shortly be placed on the English market by the Kestner Evaporator and Engineering Co., Ltd., was developed by Mr. Paul Kestner shortly before the outbreak of war, and subsequent work upon it was delayed by the German capture of Lille, so that the following description is the first to be published in this country.

The pump is of the vertical ram type, as shown in Figs. 29 and 30, which show the sectional and external views respectively, and is made of ferro-silicon. The outstanding feature is the entire absence of any stuffing box, the ram being made with an exceedingly fine clearance in the long neck of the cylinder. The leakage of acid past the ram only amounts to a drop or two per minute, and this small quantity, which remains quite constant even after long use, is returned to the suction. As a result of their being no stuffing-box and of the ram being lubricated by the acid, the efficiency of this pump is exceedingly high, namely 70% or slightly over, a figure which is not attained in any other type of pump with the exception of centrifugal pumps of large capacity.

The "Kestner" pump is made with two cylinders 4¼" diameter by 6" stroke, and works at a piston speed of 50 ft. per second.

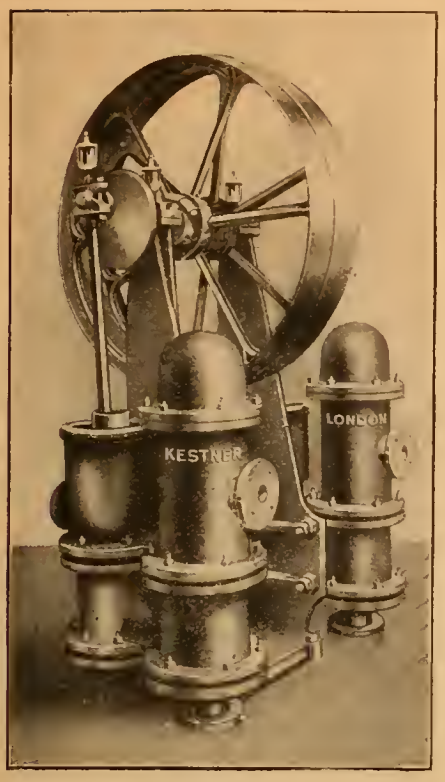
Varley's Narki Metal Ram Pump, made by John Varley and Co., Ltd., Waterloo and Atlas Foundries, St. Helens, Lancs. This pump, which is of the two-cylinder, horizontal type for belt-driving through reduction gear, has rams 3¾" diameter by 7" stroke, and will raise 2200 gallons per hour to a height of 210 ft., working at 65 strokes per minute.



Kestner Acid Pump, Section.
FIG. 29.

Section "B."—Rotary pumps for corrosive acids.

The Douglas Concentric Positive Action Rotary Pump, made by Messrs. William Douglas and Sons, Ltd., Douglas Wharf, Putney, London, S.W. 15. This pump, the construction of which is shown in Fig. 31, is made chiefly in cast-iron and gunmetal, but it can also be obtained in aluminium for special purposes. The crescent-shaped piece on the cover fits the slotted drum accurately, and the liquor is moved from the inlet side to the outlet side by the



Kestner Acid Pump (General View).
FIG. 30.

three propeller pins carried on a disc attached to the shaft. The slotted drum, which serves as a stop to separate the inlet and outlet, is driven by the pins. There are no valves, and the pump is reversible. It is made in the following sizes:—

Size.	Galls. per hr.	Speed, r.p.m.
½	70	120
¾	230	120
1	300	120
1½	750	100
2	2,100	100
3	5,000	70
4	8,200	60
5	19,750	60

Fig. 32 shows a pump coupled to an electric motor through double reduction gearing. They can also be supplied coupled direct to slow speed steam engines, or with fast and loose pulleys for belt drive.

"Ceratherm" Centrifugal Pumps, made by Guthrie and Co., Accrington. These pumps, which are made of special high tensile Ceratherm stoneware, are fully described elsewhere in this volume.

The Marclen Centrifugal Pump, made by Messrs. Marclen Pumps, Ltd., 25, Victoria Street, London, S.W. 1. These pumps are of the vertical spindle glandless drowned type, and are usually made of regulus metal in the following sizes:—

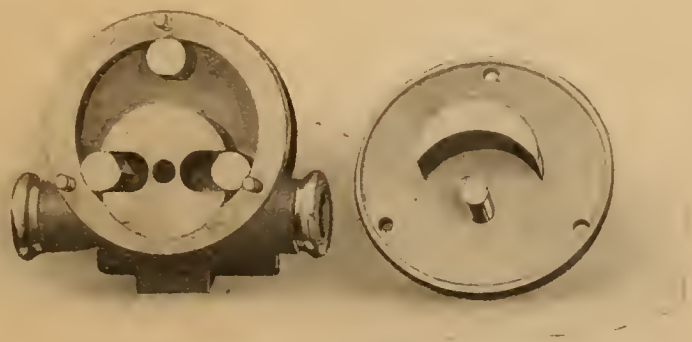
Size.	Galls. per hr.	Single stage.	Two stage.
Inches.		40′ head.	75′ head.
		Efficiency.	Efficiency.
1¼	800	16%	17%
1½	1,200	19%	23%
1½	1,600	20%	24%
1½	2,000	22%	25%
1½	2,300	23%	23%
2	2,900	25·5%	27%
2	3,300	27%	28%

The speed in all cases is 1420 r.p.m. They are fully described in another paper in this volume.

Varley's Narki Metal "Romnie" Centrifugal Pump, Fig. 33, made by John Varley and Co., Ltd., Waterloo and Atlas Foundries, St. Helens, Lancs. These pumps, all parts of which coming in contact with acid are made of Narki metal, are fitted with external ball journal and thrust bearings and extra large stuffing box. The suction is arranged axially. They are made in two sizes, one capable of lifting 20 tons of acid per hour 40 ft. at 2500 r.p.m., and the other 40 tons per hour 40 ft. at 1500 r.p.m. Fig. 31 shows one of these pumps.

Gwynnes' 2″ Regulus Metal Centrifugal Pump is illustrated in Fig. 34.

The "Ironac" Centrifugal Pumps, made by Messrs. Haughton's, Ltd., are described elsewhere in this volume.



The Douglas Pump, Internal Construction.
FIG. 31.

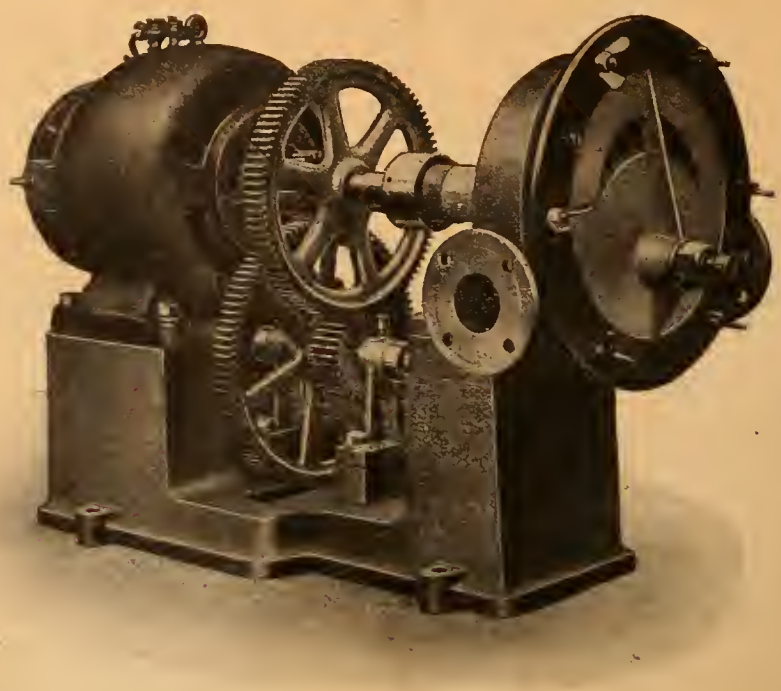
PART IV.

Pumping by compressed air.

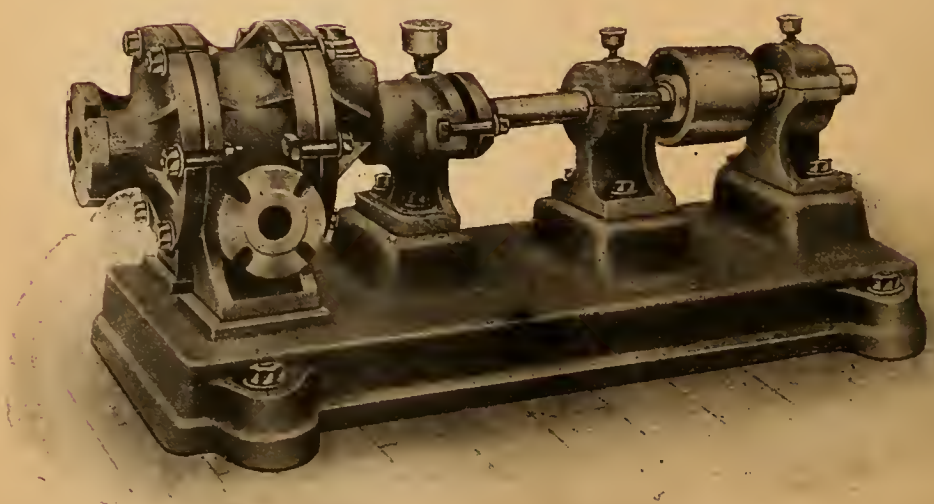
Compressed air is used for pumping in two ways, either in blow-eggs, either plain or automatic, or in air lifts.

Section "A."—Eggs or elevators.

The ordinary egg requires no special description, as it consists simply of a vessel of any convenient shape provided with an inlet pipe for the liquid controlled by a valve, a discharge pipe continued down to the lowest point in the vessel, and a compressed



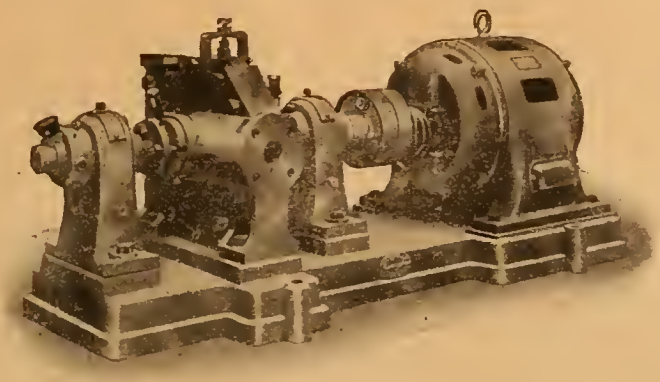
The Douglas Motor-driven Pump.
FIG. 32.



Narki Metal Centrifugal Pump.
FIG. 33.

air supply pipe. A useful point, however, that is often overlooked is that for eggs handling liquids containing solids in suspension it is a good plan to introduce the air through a perforated pipe at the bottom of the vessel, instead of at the top of the vessel, as is usually done, thus keeping the liquid agitated and preventing the accumulation of solids.

equilibrium will be maintained, provided the air supply pressure remains constant until the egg is empty, with the exception of a slight decrease in the static head owing to the lowering of the liquid level in the egg, the depth of liquid in the egg of course balancing a corresponding column in the discharge pipe.



Regulus Metal Centrifugal Pump by Gwynnes.
FIG. 34.

The efficiency of eggs and automatic elevators is a subject upon which little or no information based on actual tests is available, and it will be of interest therefore to consider how much compressed air is required for a given pumping duty and what that air represents in foot pounds of work put into the compressor, or, in other words, the overall efficiency of the system.

We will consider first an automatic elevator, where the compressed air is admitted by a float or other mechanism as soon as the liquid reaches a certain level in the egg. As soon as air is admitted pressure begins to build up and the liquid begins to rise in the delivery pipe, going on until it begins to flow out from the discharge top of the pipe. The rate at which the air pressure builds up will depend upon the size of the air inlet, but the airspace above the liquid being very small, it is safe to assume, unless a reducing valve or regulator is used, that in most cases it will reach the full pressure in the air main almost instantaneously and the column of liquid in the discharge pipe will have been accelerated up to the maximum velocity corresponding to the air pressure used by the time the liquid reaches the top of the discharge pipe. In any event equilibrium will very quickly be attained at a velocity such that the "static" head plus the friction head equals the air pressure.

For instance, if water is being blown through a straight vertical 3″ cast-iron pipe 60 ft. long, the static head is 26 lb. per sq. in., and if the air pressure were only 26 lb. per sq. in. it would just raise the water to the top of the discharge pipe without causing any delivery, while from the table of friction heads in the Appendix we see that an additional air pressure will cause a flow at the following velocities:—

Air pressure in excess of 26 lb. per sq. in.	Velocity of flow. Feet per second.
0·3	2
1·1	4
4·3	8
15·6	16

Thus if the air supply is at a pressure of 40 lb. per sq. in. the water will flow out with a velocity of about 15 ft. per second. This condition of

In automatic elevators where the air supply valve is gradually closed by a float which falls with the liquid a certain amount of wire drawing takes place, and the final air pressure may not be greater than that required to discharge the liquid with a moderate velocity—in fact, in some elevators, such as the Kestner, a regulator is provided to ensure this—but in any event the minimum amount of air used will be equal to the volume of the egg at a pressure corresponding to the dynamic head, and it may be equal to the volume of the egg at the supply pressure.

In the case of hand-operated eggs, under the best conditions, where the workman stands with his hand on the air-control valve and his ear against the discharge pipe, he is able to shut off the air immediately he hears the last of the liquid leave the egg, and he probably uses no more air than an automatic elevator, but if the man is careless, and does not shut off the air at the proper moment, the waste of air may be very considerable, as will also be the case if the egg is not filled right up with liquid.

In comparing hand-operated eggs with automatic elevators it must be remembered that the former are usually much larger than the latter, being often of 500 up to several thousand gallons capacity, as against 3 to 20, or sometimes 100 gallons in the latter, and the advantage in air economy is all in favour of one big blow instead of numerous small ones, since it is at the end of the blow that wastage occurs, and also the air clearance at the top of a large egg can be made proportionately less than in a small one.

There is, of course, no reason whatever why automatic elevator mechanism should not be applied to large eggs, but actually it is not often done. On the other hand, where a more continuous supply is required, as in the case of acid supply to towers, the use of small eggs operating frequently is necessary.

Great care should be taken in the arrangement of the discharge pipes from eggs and elevators to see that they are as nearly vertical as possible; otherwise at the end of the blow the air may break through the column of liquid and escape along the upper side of the pipe.

The necessity of reducing the clearance or airspace at the top of an egg or elevator will be

evident, since it represents so much wasted air, but it is a point often overlooked by designers.

Curves are given on the enclosed sheet showing the number of cubic feet of free air which can be compressed to various pressures by one horse-power-hour at various compressor efficiencies for single-stage compression. A curve is also given for two-stage compression at 100% or theoretical efficiency to show the saving effected by two-stage working at the higher pressures.

Another curve shows the amount of free air required to blow 1000 gallons at various pressures, this amount being equal to the volume of 1000 gallons when the air is at the given pressure, that is to say assuming the volumetric efficiency of the egg to be 100%, or the air clearance nil.

Finally, curves are given showing the efficiency of eggs when the combined compressor efficiency and volumetric egg efficiency is 100%, and also when this figure is 80%.

As an example of the use of these curves, assume that liquid is being blown against a total dynamic head of 70 ft., the air clearance of the egg being 5% of the total volume of the egg so that the volumetric efficiency is 95% and the compressor efficiency 84·2%, which gives a combined efficiency of 80%, then it can be seen from the curves that the head of 70 ft. corresponds to a pressure of just over 30 lb. per sq. in., and that at this pressure the volume of air required will be 490 cubic feet for 1000 gallons, while the air which is compressed to this pressure by one horse-power-hour is 590 cubic feet, so that 490 cubic feet will require 0·83 h.-p. hour, but the actual work done in raising 1000 gallons 70 ft. is 0·35 h.-p. hour, so the efficiency is about 42%.

In actual practice with hand-operated eggs the air will generally be at supply pressure when it is shut off, and this will mean a greater consumption of free air than is given by the curve, which represents the minimum consumption attainable by this system.

As might be expected, the efficiency of blow eggs decreases with increasing pressure, owing to the greater amount of energy contained in the air left in the egg at higher pressures.

Eggs can be obtained in many materials. There is no need to describe those made of steel or cast iron, but the homogeneous lead lining of steel eggs is a comparatively new industry in this country, and affords a very convenient type of egg for weak sulphuric acid or other corrosive liquids which do not attack lead. Steel vessels can now be lined with lead homogeneously by the Deptford Steel and Iron Works, Ltd., of 44, Kingsway, London, W.C., up to practically any size, and the lead is put out in such a way that not only will the vessels stand any pressure that the steel is capable of resisting, but also vacuum, so that these vessels can be used as vacuum receivers for use with vacuum filters, and the liquor then be blown out of them. The Kestner Evaporator and Engineering Co., Ltd., also line eggs up to 1000 gallons with lead by a homogeneous process.

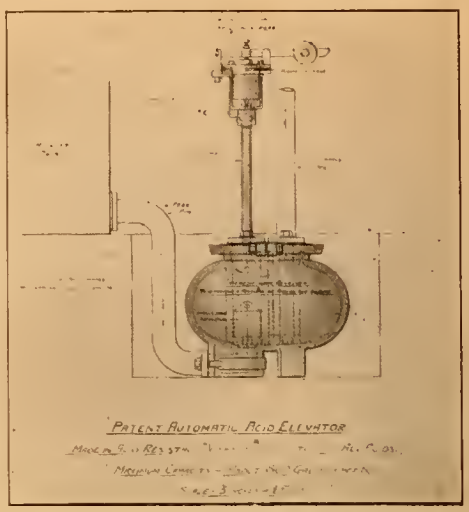
Another valuable development in lining large steel eggs is with ebonite, which can now be carried out by the New Eccles Rubber Co., Ltd., of Eccles, Manchester. Ebonite lined eggs are particularly adapted for handling hydrochloric acid.

Eggs in small sizes can be obtained in stoneware. Messrs. Doulton and Co., Ltd., of Lambeth make one of 110 gallons, in moderate sizes in ferro-silicon and regulus metal, and in all sizes in aluminium.

Automatic elevators.

The Kestner Automatic Elevators are fully described in Mr. Reavell's paper in this volume. They are made in various materials suitable for wide range of liquids and in sizes from 200 to 4000 gallons per hour.

The Ogden Automatic Acid Elevator.—This elevator, which is shown in section in Fig. 35, consists of a receiver made of "Vitreon" acid-resisting stoneware and the automatic valve gear. The apparatus is made in two sizes, capable of handling 400 and 800 gallons per hour respectively.



Ogden Automatic Acid Elevator.
FIG. 35.

There are no floats in contact with the acid, and no wires or rods. The only valve inside the receiver is a stoneware check valve on the inlet pipe.

The operation of the elevator is as follows: As the acid runs into the receiver the displaced air escapes into the discharge pipe by a small hole, just below the top flange. When the level of the acid rises above this hole, no more air can escape and a slight compression of the remaining air takes place as the acid continues to rise. This compression acts upon a fairly large rubber diaphragm placed on a chamber at the top of the air compression pipe and just lifts the valve which is attached to the piston off its seat sufficiently to allow a little compressed air to enter the piston chamber, and through it the receiver, thus starting the liquid into motion gently and without shock.

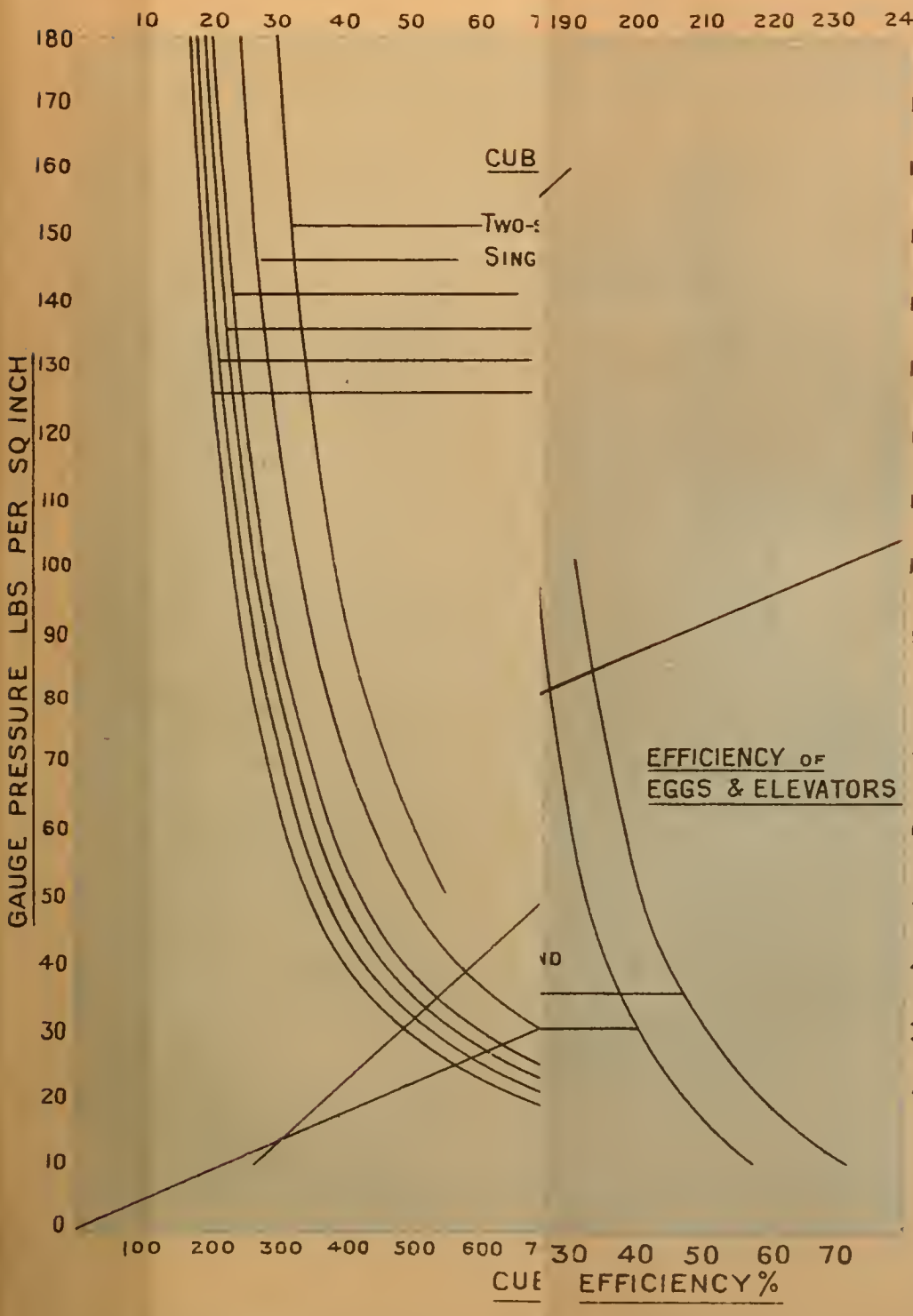
The pressure of the compressed air on the diaphragm opens the air admission valve fully, and the acid is then blown out.

As soon as the last of the acid begins to leave the discharge pipe, allowing air to escape with it, the pressure in the receiver falls, and the weighted lever at the top of the apparatus closes the air valve by acting on the piston through the rubber diaphragm. Once the air valve is closed, so that the compressed air no longer acts upon the large area of the diaphragm, but only upon the very small area of the valve, the weight of the piston is sufficient to hold the valve closed.

There is a slight space between the lever set-screws and the diaphragm set-screws, sufficient to allow the valve to lift off its seat under the slight compression of the trapped air in the receiver, as previously explained.

A minimum head of acid in the feed tank above the hole "A" equivalent to 6″ of water is sufficient to operate the air valve.

As a rule, if the valve gear is below the level of the acid in the feed tank, a non-return valve is provided in the compressed air pipe, so that in the event of the air supply failing the acid will not rise up in the air compression pipe and reach the valve gear.



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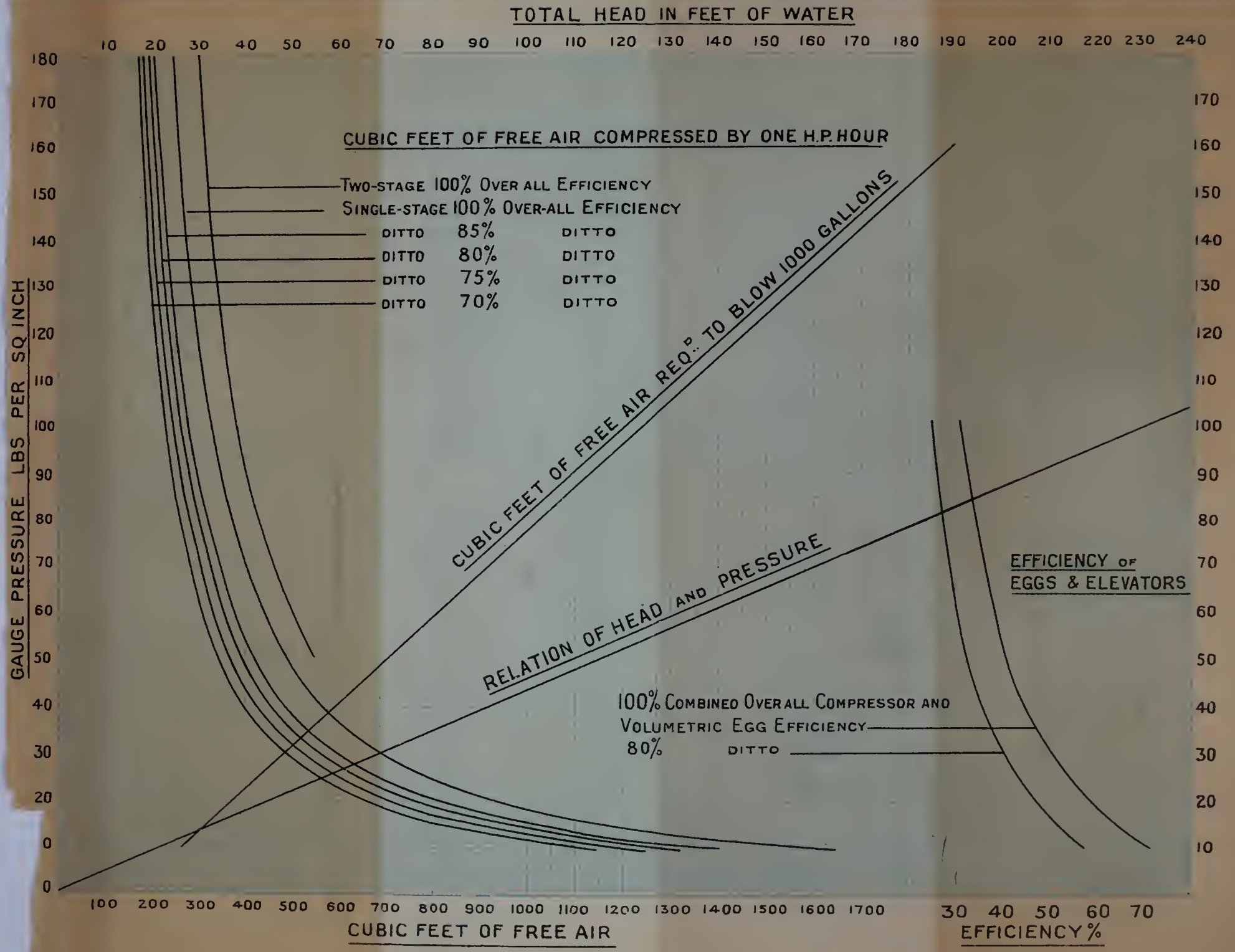
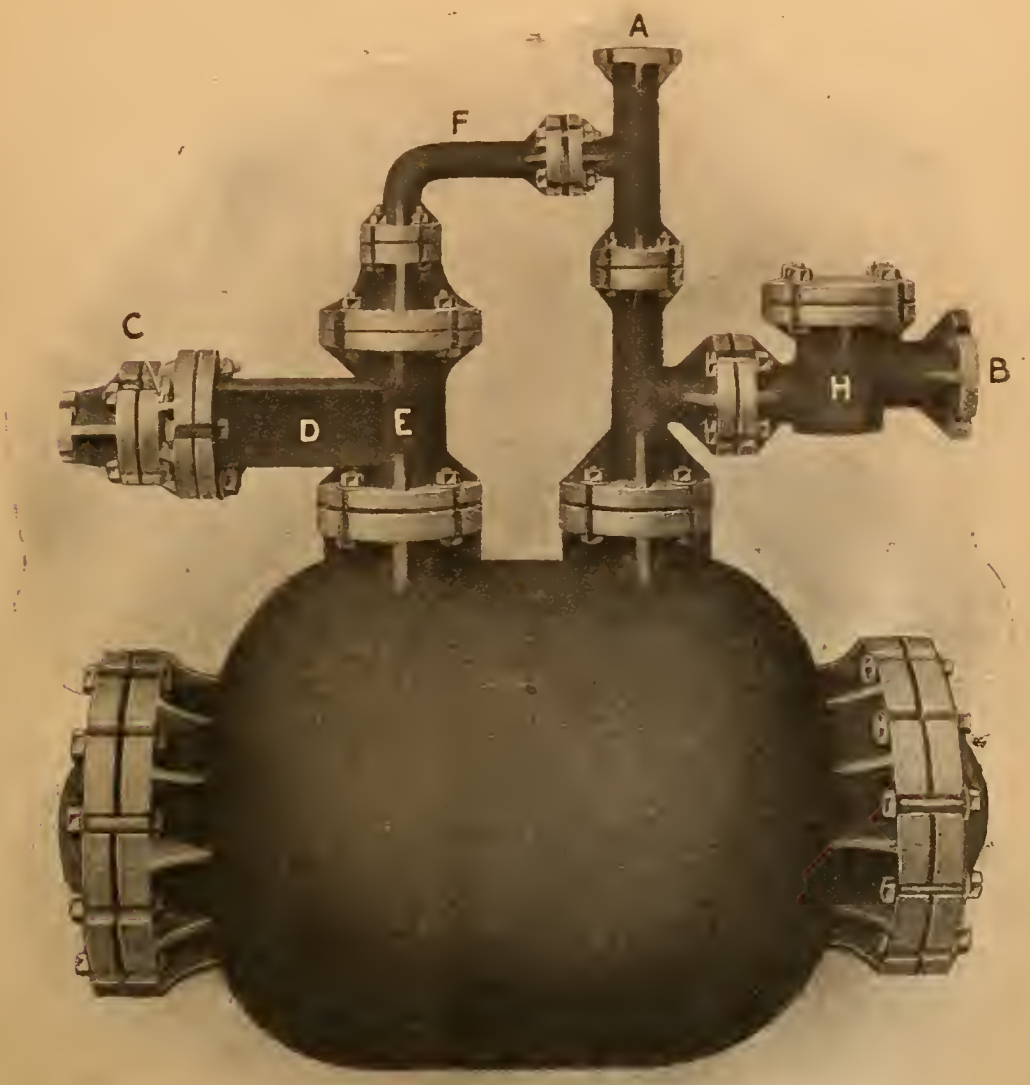

TOTAL HEAD IN FEET OF WATER
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240
GAUGE PRESSURE LBS PER SQ INCH
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 0
CUBIC FEET OF FREE AIR COMPRESSED BY ONE H.P. HOUR
TWO-STAGE 100% OVER ALL EFFICIENCY
SINGLE-STAGE 100% OVER-ALL EFFICIENCY
DITTO 85% DITTO
DITTO 80% DITTO
DITTO 75% DITTO
DITTO 70% DITTO
CUBIC FEET OF FREE AIR REQ.D TO BLOW 1000 GALLONS
RELATION OF HEAD AND PRESSURE
EFFICIENCY OF EGGS & ELEVATORS
100% COMBINED OVER ALL COMPRESSOR AND VOLUMETRIC EGG EFFICIENCY
80% DITTO
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700
CUBIC FEET OF FREE AIR
30 40 50 60 70
EFFICIENCY %

An important point in regard to this elevator is that it will work even if the acid only trickles in.

This type of automatic discharge gear can obviously be fitted to existing eggs of any type.

Barnes' Patent Automatic Elevator is made by Messrs. John Varley and Co., Ltd., of St. Helens. Fig. 36 shows this elevator constructed entirely of trap with delivery of the condensed water to a height of 60 ft. to the pumping of acids. It will take liquids from vessels under a pressure of 20 lb. per sq. in. or under a vacuum and will handle boiling liquids as well as cold ones, and will operate with steam or compressed air or any pressure from 30 to 200 lb.



Barnes' Patent Automatic Elevator.
FIG. 36.

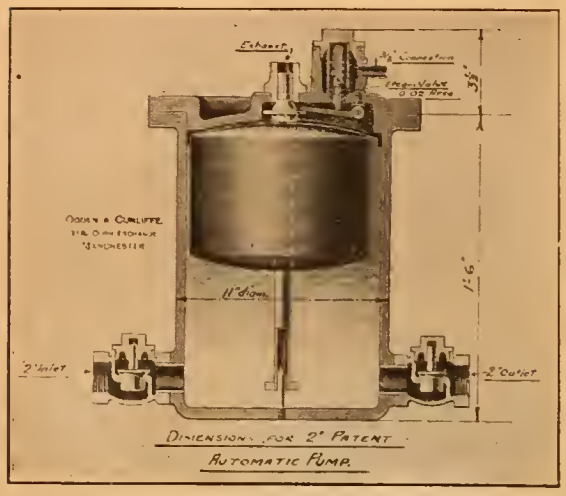
Narki metal, with a capacity of 800 gallons per hour. The acid enters through the pipe, B, and when the egg is full a float in E closes the vent pipe, F, at the same time operating a lever in D, which open the air valve in C. The air pressure closes the non-return valve, H, and forces the acid up the discharge pipe, A. This apparatus is also constructed in regulus metal, with a capacity of 900 galls. per hour.

The Ogden Automatic Pump Trap.—This useful apparatus is a form of automatic elevator adapted to a variety of uses, ranging from that of a steam

The apparatus, shown in Fig. 37, consists of a cylindrical vessel containing a float usually made of welded steel or of stoneware for use with acids. The inlet and outlet pipes at the bottom of the vessels are provided with non-return valves.

The operation of the pump is as follows: As the liquid rises in the vessel it carries up the float until this engages with the exhaust or equilibrium valve and partially closes it, at the same time actuating a lever which slightly opens the steam or compressed air valve. The steam or compressed air then closes the exhaust valve completely, at the same time fully

opening its own admission valve, after which the liquid is blown out of the vessel. The float forms an efficient separation between the steam and the liquid, thus reducing condensation to a minimum. When the vessel is almost empty the float comes down upon a collar upon the central tubular guide, which is attached to the exhaust valve, and thereby opens this valve, and at the same time releases the lever of the steam inlet valve, which is closed.



Ogden Automatic Pump Trap.
Fig. 37.

If the apparatus is acting upon atmospheric pressure the exhaust takes place to atmosphere, but if the feed vessel is under vacuum the exhaust pipe leads back to it, thus placing the apparatus in equilibrium with the feed vessel, and allowing liquid to flow into the apparatus again, when the cycle recommences.

This pump trap is made in three sizes, capable of dealing with 300, 600, and 1200 gallons per hour respectively.

There are obviously a great many different uses for this apparatus in and about a chemical works, from draining pits and excavations, and returning condensed water from ordinary steam traps to the boiler house hot well, to raising chemical liquors, oils, or petrol.

The air lift.

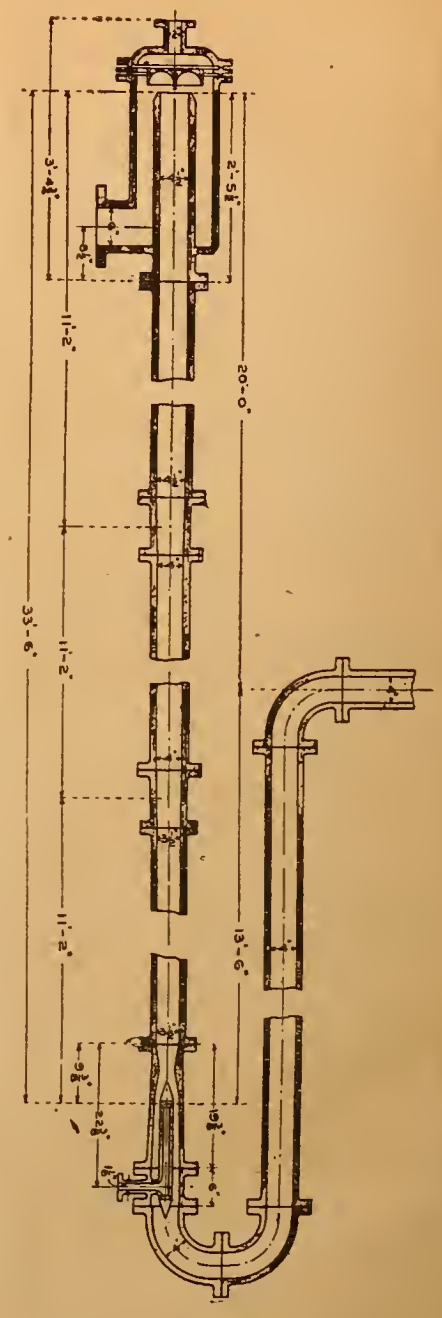
The air lift provides an exceeding simple method of raising liquids, and one that yields a very fair efficiency if the design is properly carried out by experienced people. It is not used in chemical works to anything like the extent it deserves.

The principle of the air lift is too well known to require detailed description, consisting of the injection of compressed air at the bottom of a discharge pipe, so that alternate piston-like layers of air and water are formed in the pipe, thus lightening the column in the pipe and allowing the liquid to be blown out with an air pressure, which may be as low as $\frac{1}{3}$ lb. to $\frac{1}{4}$ lb. per foot of actual lift with water. In starting the air lift, of course an air pressure sufficient to blow out the solid column of liquid must be available.

The use of air lifts with hot liquids offers special advantages, since the heat energy of the liquid contributes to the work of pumping by expanding the air, and pumping efficiencies of 100% and over can be obtained in this way. Air lifts are also used for lifting molten metals, and in such cases the thermal expansion of the air will be still more marked owing to the higher temperatures.

Those interested in the use of compressed air for raising liquids otherwise than by eggs will find much valuable information in the following places:—

Browne, Behr, and Randall, Engineering News, June 8, 1893.



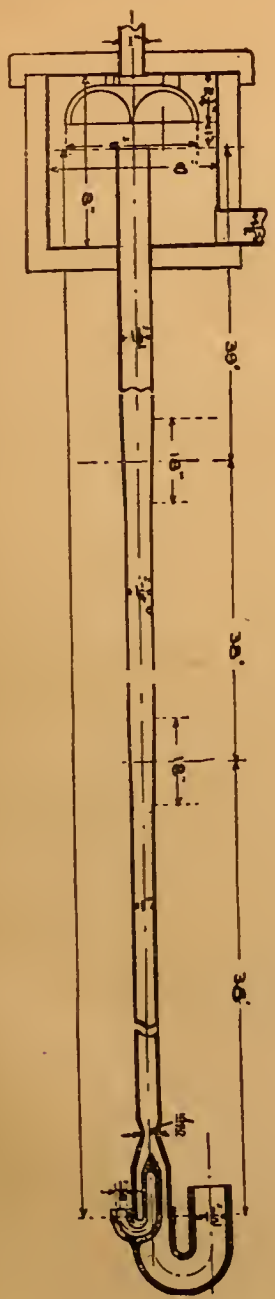
Sullivan Air Lift in Cast Iron, Section.
Fig. 38A.

Pumping by Compressed Air, by E. M. Ivens. (Chapman and Hall, 1914.)

Air Lift Pumping, by A. W. Purchas, Proc. Inst. Mech.E., 1917.

The correct proportioning of the "submergence," or ratio of the depth below the free level of the liquid in the well or feed tank at which the air is applied, to the total lift has much to do with the

efficiency of an air lift, and while no hard and fast rules for determining this factor can be given, since it depends to some extent upon the size of the eduction pipe and the nature of the liquid, it is generally admitted that the lower the lift the greater should be the submergence, and that the greater the submergence the higher the efficiency.



Sullivan Air Lift in Lead. Section.
FIG. 38B.

For lifts up to 100 ft. the submergence will usually lie between 50% and 70% of the lift, decreasing to about 35% with a lift of 500 ft.

Efficiencies of over 30 can generally be obtained with a well-designed air lift, and 40% or even higher can be reached in some cases with cold liquids.

The following description of some large air lifts made by the Sullivan Machinery Company, of Chicago and Salisbury House, London Wall, E.C., for handling nitric acid on two of the United States Government atmospheric nitrogen plants at Sheffield, Alabama, may be of interest.

The Sullivan Air Lift.—These large air lifts, involving lift pipes 3″ or more in bore, and therefore comparable with the air lifts used in this country for raising water from deep wells, are made in various materials, and are used for sulphuric and other acids, as well as nitric acids.

Fig. 38A shows section of standard apparatus made in cast iron, and 38B in lead. The apparatus consists of the feed pipe, foot piece containing air-jets, the delivery pipe, and the separator head, where the liquid is separated from the accompanying air.

Coming now to the atmospheric nitrogen installations, there were two plants in operation. In plant No. 1 a series of towers 60 ft. high were to be supplied with acid, and a compound or double lift was used. The foot pieces were placed in a pit 20 ft. deep, and the first lift raised the acid to a height of 20 ft. above the ground, a submergence of 50% being adopted. After passing through the separator heads the acid flowed down to a second set of foot pieces at the bottom of the pit, from which it was lifted to the top of the towers. Air at a pressure of 40 lb. per sq. in. was used, and it was claimed that the power consumption was no greater than with a single lift, owing to the lower pressure required.

The air compressor plant was of four units, each giving 1500 cub. ft. of air per minute.

In plant No. 2 a series of towers 70 ft. high had to be supplied with 50 galls. per minute of acid each. A single lift system was used, and the foot pieces, to a number of 120, were placed at the bottom of 12″ cast-iron tubes sunk in the ground to a depth of 100 feet. The lift pipes were made of ferro-silicon of 3″ bore, and the air supply pipes were 1¼″ bore aluminium. The air, at a pressure of 100 lb. per sq. in., was supplied by six compound compressors each giving 2600 cub. ft. per minute.

The pumping efficiency of these air lifts ranges from 30% to 35%.

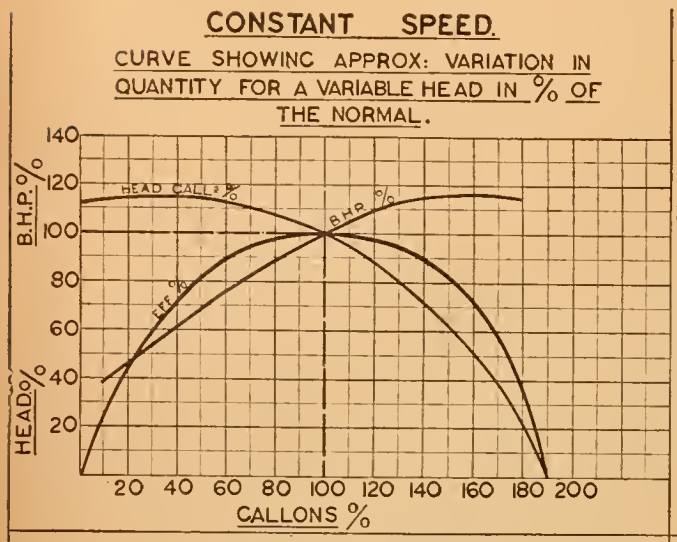
A very interesting system of applying compressed air to pumping problems is that known as the **return-air system** in America. It consists in using reciprocating pumps of the steam-driven type, but with compressed air instead of steam, and on the closed circuit system; that is to say, that the exhaust from the pumps goes back to the compressor and is used over and over again.

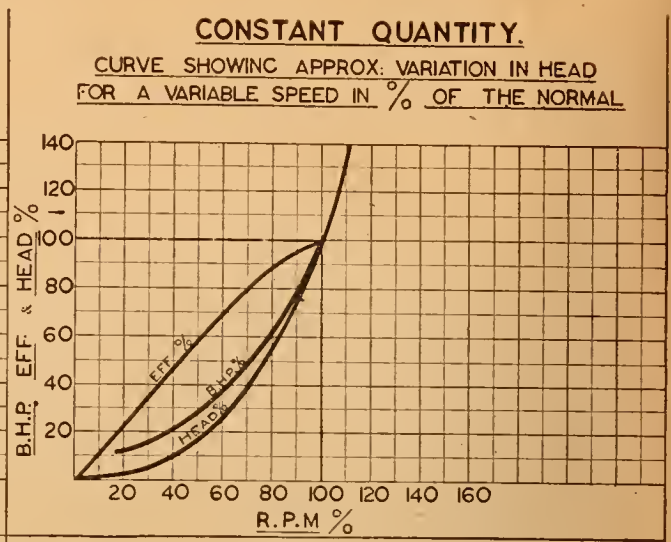
This method enables advantage to be taken of the economy in compression at the higher pressures. For instance, if a pump took 100 cub. ft. of free air per minute at 60 lb. pressure, exhausting at atmospheric pressure, it would require an expenditure of 13·4 h.p. at the compressor, whereas if the air were delivered at 90 lb. pressure and exhausted at 30 lb. the consumption of power would only be 8·5 h.p.

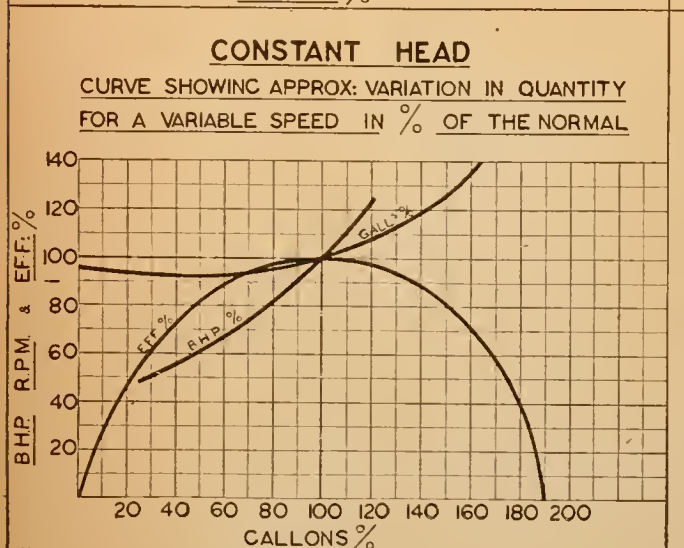
In this system any losses of air through leakage are made up by a small booster compressor, and it is obvious that slip past the air piston in the pump will not cause loss in the same way as in the case of air or steam exhausting to atmosphere, since the exhaust pressure goes back to the compressor.

This paper would not be complete without a reference to **steam ejectors**, which are often useful in chemical works for draining pits and pumps. These can be obtained in iron, gunmetal, ebonite, stoneware, regulus metal, and ferro-silicon. They are cheap and easily put up, but their low efficiency is against their use except for the purposes named.

APPENDIX.







Curves of Centrifugal Pumps (see page 52).
FIG. 39.

General data.

An imperial gallon of water at 62° F. (16·6° C.) weighs 10 lb. and occupies 277·42 cub. in., or 0·16054 cub. ft.

A cubic foot of water at 16·6° C. weighs 62·289 lb.

A cubic foot of sea water weighs 64 lbs.

An imperial gallon=1·2 United States gallon=4·536 litres.

A United States gallon=231 cub. in.=0·833 imperial gall.

A litre=0·22 imperial gall.=0·26 U.S. gall.=61·16 cub. in.

One cubic metre=220 imperial galls.

A ton of water=224 galls.=35·96 cub. ft.

A head of 1 ft. of water=a pressure of 0·4325 lb. per sq. in.

A horsepower with 100% efficiency will raise 1980 galls. per hour 100 ft.

A kilowatt with 100% efficiency will raise 2654 galls. per hour 100 ft.

To find a discharge of a reciprocating single-cylinder pump in gallons per hour, multiply the square of the diameter of the cylinder in inches by twice the mean piston speed in feet per minute. This allows about 2% for loss from slip. In case of single-acting ram pumps only the effective strokes must be taken in calculating the mean speed.

Example:—What will be the discharge of a 6″ pump with a mean piston speed of 80 ft. per minute?

Answer:—6″×6″×80×2=5760 galls. per hour.

Example:—What will be the discharge of a 4″ single-acting pump making 40 9″ strokes per minute?

Answer:—4″ × 4″ × 0·75 × 40 × 2=960 galls. per hour.

Flow of water through full pipes:—

The following formulæ are, in a slightly simplified form, those prepared by Mr. A. A. Barnes from the results of actual tests:—

h=head absorbed in friction in feet.

v=velocity of flow in feet per second.

d=bore of pipe in inches.

l=length of pipe in feet.

For uncoated cast iron pipes.

$$v = 13{\cdot}39 d^{\cdot 600} \left(\frac{h}{l}\right)^{\cdot 512}, \quad h = \frac{{\cdot}0063\, l v^{1{\cdot}953}}{d^{1{\cdot}172}}$$

For uncoated steel welded pipes.

$$v = 14{\cdot}08 d^{\cdot 652} \left(\frac{h}{l}\right)^{\cdot 528}, \quad h = \frac{{\cdot}00668\, l v^{1{\cdot}894}}{d^{1{\cdot}235}}$$

For clean lead pipes.

$$v = 16{\cdot}81 d^{\cdot 679} \left(\frac{h}{l}\right)^{\cdot 591}, \quad h = \frac{{\cdot}00844\, l v^{1{\cdot}692}}{d^{1{\cdot}149}}$$

For clean glass pipes.

$$v = 16{\cdot}24 d^{\cdot 562} \left(\frac{h}{l}\right)^{\cdot 556}, \quad h = \frac{{\cdot}0027\, l v^{1{\cdot}799}}{d^{1{\cdot}011}}$$

The same approximate formula as given for pumps may be used for ascertaining the discharge

of water from pipes, namely, multiply the square of the diameter of the pipe in inches by twice the velocity in feet per minute, and the result will be the discharge in gallons per hour. The exact factor is 2·038.

Table of pipe equivalents.

Taking into account the relatively greater friction in small pipes: —

	¼″	⅜″	1″	1½″	2″	2½″	3″	4″	5″	6″	7″	8″	9″
1″	5·9	2·1											
1½″	16·6	5·9	2·8										
2″	34·5	12·2	5·9	2·1									
2½″	61	21·6	10·3	3·7	1·8								
3″	97	34·3	16·4	5·8	2·8	1·6							
4″	201	71	34	12	5·8	3·3	2·1						
5″		125	60	21	10·3	5·8	3·7	1·8					
6″		199	96	34	16·3	9·2	5·8	2·8	1·6				
7″				50	24	13·7	8·6	4·1	2·3	1·5			
8″				70	34	19	12	5·8	3·3	2·1	1·4		
9″				95	46·	26	16	7·8	4·4	2·8	1·9	1·3	
10″				124	60	34	21	10·2	5·8	3·6	2·5	1·8	1·3
12″					94	53	34	16	9·2	5·8	3·9	2·4	2·1

Example: —One 8″ pipe is equivalent to 34×2″, or 12×3″ pipes.

Discussion.

Capt. Goodwin described the method adopted in a large acid plant in America. The quantities were very large, about 200 tons per hour, and the method was simply to use a passenger lift; after all, the efficiency of the ordinary mechanical lift was over 80% or more. It had not come into general use in chemical works, but it was justified in such large plants as he referred to. He hoped that the Humphrey pump would be studied as it deserved to be, and that it might be developed in one form or another. Another method was the use of the vacuum for moving liquids. On the face of it it might seem rather irrational to use vacuum, as it was more efficient to compress air. In certain cases, however, it gave advantages due to the absence of floats. He had used it successfully in explosive works. In its simplest form it would consist of a receiver and suction pipe dipping into the tank with a suitable non-return valve on the suction pipe. The possible head was limited to 30 ft. in the case of water or less for heavier liquids. The use of vacuum had considerable advantages in the moving of liquid from one vessel to another in the course of continuous processes. In connection with the distribution of liquids in chemical works he urged the necessity of paying more attention to the standardisation of pipe lines and of distances between the flanges of cocks and valves to facilitate replacements and reduce the number of spare parts to be kept in stock. Again, the pipe lines ought to be painted in distinctive colours; in some Government plants that had been done. The great need was for standard colours to be used by all works, otherwise men changing from one works to another might be liable to cause accidents. The capacity of storage vessels ought to be standardised and also flange connections to the various pumps, so that when a pump gave out it would be an easy matter to replace it by a pump of another make about the works.

Mr. Reavell asked what use the rubber diaphragm was in the acid elevator (Cunliffe) if used for nitric acid.

Mr. Cunliffe replied that they were not bound to use a rubber diaphragm.

Mr. Reavell said that there seemed to be an impression that all the Kestner elevators had to be filled quickly. That was not so; they had more than one type, including those which could be filled extremely slowly.

PUMPING ACIDS AND OTHER CORROSIVE LIQUIDS, WITH PARTICULAR REFERENCE TO THE ARMOURED CERATHERM CENTRIFUGAL PUMP.

BY W. HAYHURST.

The problem dealt with in this paper is the construction of pumps of a type suitable for any acid or corrosive liquid in whatever conditions may be encountered in a chemical or other works.

Certain qualifications must be provided for in such pumps. If possible there should be no rubbing surfaces or bearings within the pump; there should be no material touched by the corrosive liquid passing through the pump which can be dissolved or affected by that liquid; valves cause wear and tear, require frequent attention, and should be avoided if possible. Any oil used should not come into contact with the corrosive liquid, accidents fatal not only to the pump having been traced to such conditions. The pressure developed by the pump should be easily variable from zero to about 50—60 lb. The greatest importance should be attached to the simplicity of the apparatus used, so that there is little or nothing to go wrong and the apparatus should be suitable for continuous running.

The heads or pressure developed by the pump should be accomplished at comparatively low pressures.

The type of pump which fulfils the requirements of the chemical trade is the centrifugal. It is possible to construct a centrifugal pump without any valve, without rubbing surfaces, and as will be seen later, to obtain the various heads or pressures, and meet the different conditions required in a manner free from complication which will give efficient results with the minimum of attention.

What materials are available to the chemical engineer for manufacturing such centrifugal pumps? Enamelled ware is out of the question, because the slightest scratch would terminate the life of the pump. There are two factors to consider in the choice of material. One is corrosion and the other erosion. The later factor would probably make it impossible to use enamelled ware pumps, however carefully fitted. Ebonite pumps are not suitable for hot liquids, and the number of corrosive liquids on which they could be used is strictly limited; *e.g.*, liquids containing chlorine. They have the disadvantage, moreover, that any rubbing surfaces—at the gland, for example—are liable to seize owing to the local heating so rapidly generated by any friction. The pumps manufactured from ferro-silicon or other alloys have only a very restricted application, being unsuitable for hydrochloric acid, also any process where contamination by iron would be detrimental. They are unsuitable for many solutions containing metallic salts, and for many warm, weak mineral acids when they contain traces of impurity. They are quite unsuitable for most organic acids, and there is considerable difficulty in making suitable pump castings. Lead and regulus metal, of course, are very strictly limited in their application, and are unsuitable for many acids and for solutions containing metallic salts. Such expensive metals as gold and platinum would not be insoluble in all the acids and liquids met with in chemical practice, and the factor of erosion might be very serious. Such manufacture, however, would not be altogether out of the question, because centrifugal pumps with impellers of very small dimensions, say of only two or three inches diameter, could be made which would lift to any head required in the chemical works, as much as 700 ft. head having been obtained by these small impellers. But the difficulty of high speed in the neighbourhood of 10,000

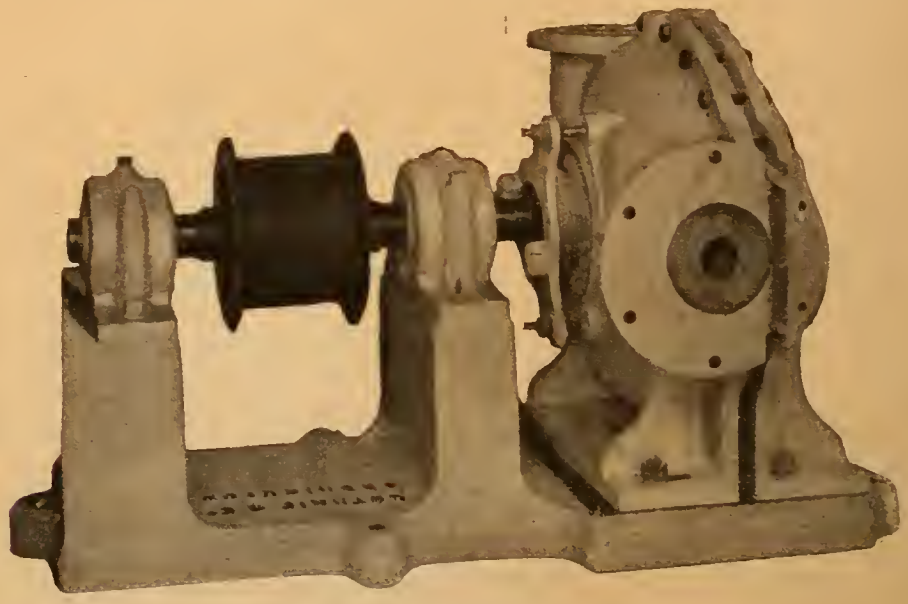
revs. per minute, as well as cost, discounts the possibilities in this direction, although they are rather interesting.

Providing that it can be obtained in suitable forms, ceramic material offers the largest possibilities for the construction of pumps for the chemical trade. Ceramic material can be obtained which is quite insoluble in almost any corrosive liquid. The hard nature of the product also reduces wear due to erosion to the minimum. The type of ceramic material chosen by the writer for his pump was a form of "ceratherm." Ceratherm is a new acid-ware, which was prepared during the war for rapid condensation of large quantities of acid gas in the manufacture of explosives. It has useful properties which make it suitable for this work in that small articles can be heated to a red heat and plunged into cold water without cracking, and it conducts heat much more quickly than ordinary stoneware, thus enabling an equable temperature to be maintained throughout any apparatus into which it is made. A blow on a piece of ceratherm does not produce the same shattering effect as on a piece of glass or a piece of highly vitreous stoneware.

The type of ceratherm used for the manufacture of pumps, however, was not the same as that used for the manufacture of Hart's nitric acid condensing plant, for instance, used in the manufacture of explosives, but a type was prepared with considerably increased tensile strength. Sufficient of the heat-resisting capacity of the original form of ceratherm has been retained to enable the pump to be worked alternately on hot or cold liquids without any liability to fracture. Other advantages are that the new type of ceratherm can be manufactured more accurately, and lends itself to the preparation of very thick, strong apparatus. The ceratherm is, of course, entirely unaffected by practically any chemical.

Before dealing with the method of construction of the latest form of armoured ceratherm centrifugal pump, it will be useful to refer to the old type of earthenware centrifugal pump, such as was made in Germany. This type bears no comparison whatever with the new pump. The bodies are thin and comparatively weak. The impellers are slight in construction. The design of the pump is such as to subject it to unnecessary strain in coupling. There is a tendency for pressure to build up behind the impeller and cause leak at the gland. They are quite unsuitable for anything but low lifts. The Guthrie pump is identical in many respects with the German type imported into this country shortly before the war with the exception of the fact that it is made of ceratherm, and therefore is more suitable for hot liquids or variable temperatures, a condition which was likely to crack the German pump; and the method of putting the impeller on to the shaft is quite different from the German. This method will be explained later in the paper. The Germans often used sulphur cements for their armourings and for putting the impellers on the shaft. This was a very bad feature indeed, and in many cases lead to the complete failure of the pump.

I now refer to the Guthrie Ceratherm Pump. The examples shown illustrate the method now in use in the manufacture of these pumps. Attention should be directed to the following points:—



Armoured Guthrie Ceratherm Pump (belt-driven).
FIG. 1.

1. The casings are made exceedingly thick and strong. They are set into the iron armourings by means of one of the cements manufactured by the same firm, which has been found most suitable for this particular purpose, and which itself possesses remarkable acid-resisting properties.

2. The inlet and outlet of the pump are so constructed that coupling up can be accomplished without any fear of damaging the pump, and the ceratherm is only subjected to crushing strains to which it has considerable resistance.

3. The acid or corrosive liquid is fed into the pump on the gland side. No trouble whatever is experienced in packing this gland, which is continually under suction, and a small quantity of wool soaked or not soaked, as may be desired, in paraffin wax and pressed home with the fingers provides all that is necessary. The gland packing need not be very tight to obtain quite efficient results without any leak. In fact, heads of 200 or 300 ft. can be attained without the slightest leak or trouble at the gland. These casings are found most efficient in use and will withstand many times the pressure to which they are normally required to be subjected.

The writer has personally tested casings up to 130 lb. pressure, which of course is much beyond what is normally required.

Various types of impellers have been used in these pumps. There is the closed type, the Manx type (so called from its likeness to the Isle of Man coat of arms), the Perforated type, and the Crippled type where only very small quantities are required.

Armoured Guthrie Ceratherm Pump. View of inlet half with impeller removed.
FIG. 2.

Armoured Guthrie Ceratherm Pump. Inlet half with impeller in position.
FIG. 3.

The fixing of the impellers on to the steel shaft is a matter which requires very careful consideration, and after some experimenting the method adopted was to prepare a cementing material of very high acid resistance to fill the interior of the shaft of the impeller. This material receives a screw thread, and the shaft is then screwed into the impeller, which is ground and balanced on its own shaft.

From being one of the weakest features of the old German type of pump, this method of connecting the ceramic portion to the steel shaft has now become one of the strongest and most satisfactory features of the pump.

The impellers, it will be noted, are of very substantial construction. They have been tested up to fully 3000 revolutions, and as they are normally never required to be run above the neighbourhood of 1500 revolutions, it will be seen that the safety factors are very high.

Armoured Guthrie Ceratherm Pump. View of impeller.
FIG. 4.

The Manx impeller, which is so far as we are aware entirely new in idea, is almost self-balancing so far as thrust is concerned, and gives very little thrust along the shaft. With the closed type of impeller in some conditions considerable thrust may be developed, which gives the usual trouble with thrust bearings. The thrust bearings which are used whenever closed type of impellers are supplied are of very substantial character, and much above the work required.

The tendency at present is that in the Guthrie Ceratherm Pump the Manx type of impeller is almost always supplied and special thrust bearings are not necessary.

In considering the results obtained with Armoured Ceratherm Centrifugal Pumps it should be borne in mind that the conditions required by the chemical trade for centrifugal pumps are exceedingly severe. It is generally required to pump a small quantity, say, from 20 to 100 gallons a minute to a head of anything up to 120 ft., whilst running the pump at low revolutions. This means that the ratio of the diameter of the impeller to the width of its blade is necessarily high, and as this ratio is a factor which governs the theoretical efficiency of any centrifugal pump a corresponding reduction of efficiency would be expected.

Notwithstanding these conditions the efficiencies obtained with the Armoured Ceratherm Centrifugal Pump, as seen in the type of results indicated below, are of a satisfactory order.

In the neighbourhood of 40 ft. head efficiencies of 60% have been attained. In the neighbourhod of 120 ft. head efficiencies of the order of 40% have been obtained even with the diminished quantities required by the acid trade. If large quantities are

required very high efficiencies could probably be attained at high heads, say, in the neighbourhood of 70%.

	Revolutions.	Head, ft.	Quantity. Galls. per min.	H.P.	Efficiency. %
N1	1750	116	160	13¼	43
N2	1400	87	110	6	48·3
N3	1750	128	120	12¼	38
N4	1000	35	160	2¾	62
Q	1665	35	150	2¼	71
Q1	1450	35	100	1¼	60

De Laval gives the general efficiency of centrifugal pumps below 500 galls. capacity per minute as not more than about 55%. Taking all factors into consideration, the efficiency of the Armoured Ceratherm Centrifugal Pump is remarkably good. Of course, for very small quantities at high heads a diminution of efficiency must be expected, but it is never more than one would expect from the diminution in quantity.

The highest head which has been attained with the pump shown and the impeller shown is 300 ft., which corresponds to 130 lb. pressure in the casing. This pump has been continuously run at 170 ft. head, yielding at that head about 80 galls. per minute.

The experience referred to in this paper has been obtained on a practical scale in actual work, and the following liquids have been pumped with success:—Sodium peroxide, hot and cold solution; this is one of the most troublesome substances to pump. A metallic pump of any description whatever would be useless; in fact, I do not know any other pump which would answer the purpose. The slightest particle of metal given up would pass into the process which this pump is feeding and do considerable damage. Hydrochloric acid is being pumped, both hot and cold. Nitric acid of various strengths and different temperatures and containing various impurities. Solutions of metallic salts, acetic acid. There is still a good deal of scepticism amongst manufacturers as to whether their particular liquid can be pumped without any harm being done. The makers of this pump would be very glad indeed to find a liquid which they cannot pump satisfactorily.

In conclusion, the fact that any acid or corrosive liquid can now be pumped with safety to any head met with in the chemical works should be of assistance in the development of new processes for the washing of gases, condensation, and absorption.

Discussion.

Mr. Rudge remarked that it seemed to him that most of the types described needed a separate motor. He thought there was a lot to be said for one motor in an establishment.

Mr. H. M. Ridge said that Mr. Hayhurst had emphasised the tensile strength of his material. He asked for some information on the tensile tests not done on fragments cut, ground, or sawn, but practical tests. Another point was the heat difference. He had given some references to the heating of a vessel with a metal outside and lined with ceratherm. Was the coefficient of expansion of the ceratherm identical with that of cast iron or mild steel, or whatever was used? Another point he would like to hear more about was the conductivity.

Mr. Hayhurst said that figures for tensile strength were not easy to give, but in his opinion the proper way to get an idea of what ceratherm would stand was to run it until it burst, and they would get the tensile strength. He had not succeeded in bursting one yet. He had given a figure of 3000 revolutions for the larger impellers, and that gave a safety factor at once of four or more. He did not think there was any other really reliable way of getting a figure. After all, the question was: How do they work and how do they stand up in use. They had run impellers faster than they ought to and they did not break. The transmission of heat was based on figures from actual practice, using a lead coil. It was in use and transmitting heat quite satisfactorily. He had not yet had an opportunity of taking accurate readings. So far as the question of linings being affected by different coefficients was concerned, the linings were fluted on, and they had never had one come off in use.

The following paper was taken as read:—

HANDLING OF PETROLEUM IN BULK AT THAMES HAVEN.

BY N. A. ANFILOGOFF, F.I.C., M.I.MECH.E.

The Petroleum Storage Wharf at Thames Haven has been inseparably connected with the petroleum industry of this country from its inception. Starting as it did as a barrel warehouse, it has grown with the industry, changing its aspect with that of the industry as a whole, and always keeping just ahead of the phases in the trade itself, until to-day the storage tanks of the London and Thames Haven Oil Wharves, Limited, which have a capacity of over 500,000 tons, cater for the whole of the trade, making Thames Haven Wharf the largest petroleum bulk storage installation in the world. The modern tank steamer brings petroleum from every part of the globe. It is able to carry a large number of grades in its separate and distinct tanks on board ship. It is taken alongside any one of the four deep-water piers, and there expeditiously empties its cargo through various pipe lines into the storage tanks on the wharf. In the main the operations are alike, whether the steamer brings the refined petrol or the very viscous petroleum residues used as flux for road-making. The steamer pipe lines are connected to the shore mains by means of flexible hose, and the ship discharges its several grades with its own pumps.

For high-flash petroleum the ship's pumps are supplied with steam generated on board ship, while for discharging low-flash petrol or crude oils steam is supplied from shore, because no fires or naked lights of any description are permitted on board while handling low-flash petroleum. From the engineer's point of view it would, at first blush, appear a great waste of steam if he were told that the shore boiler is somewhere about 800 to 1,000 ft. away from the ship's pumps, and that the steam had to be conveyed there. This was so, and in the early stages the pumps were practically worked "hydraulically," for the low-pressure steam, used some 17 years ago, arrived at the steam cylinder of the pump on board ship practically little more than hot water. It was, nevertheless, expedient, as it obviated risks from fire. This will be readily understood, seeing that when a tanker is loading or discharging low-flash petroleum evaporation is going on the whole while. Petroleum vapour being much heavier than air, this inflammable gas pours down into the stoke hole and low-lying holds in the ship, where, with fires under the boilers, it may easily ignite and convey the flames to the tanks themselves. If during its progress petroleum vapour becomes diluted with air, it is even more dangerous, as it may then form an explosive mixture.

In the course of time expediency alone did not satisfy the management, and the uneconomic expenditure of steam was inquired into. This was finally overcome by providing high-pressure boilers with superheaters, which were calculated to give sufficient superheat to insure the steam arriving at the tanker's pump cylinder at a temperature not less than that of saturated steam of that pressure. To achieve this object the calculation employed was that for every 3 ft. of efficiently lagged

steam main the superheated steam would lose one degree of its superheat. Thus for 900 ft. of steam main 300° F. superheat would have been necessary. In practice, however, it was found that steam with 160 lb. gauge pressure and a superheat of 140° F. travelled through a 3-in. main a distance of 850 ft., and at the end there was registered a pressure of 118 lb. per square inch and a temperature of 378° F., *i.e.* still showing some 20° F. superheat above the temperature of saturated steam. The loss of superheat worked out at about 1° F. for every 7 ft. of main. No hard and fast rules can, however, be laid down, so many factors influencing the greater or lesser loss of superheat, amongst which lagging, atmospheric conditions, steam consumption, velocity, and friction are worthy of mention.

When the cargo is discharged into the storage tanks of the ocean depot or installation the various products, in addition to those obtained from refined operations, have to be transported either direct to consumers or to inland or smaller depots for distribution. This is carried out by means of the ubiquitous square petrol can, by wood or galvanised steel barrels and drums, by either horse-drawn or self-propelled road tank car, by rail tank car, by towed bulk tank barges, or by small coasting tank steamers. At Thames Haven, where during 1918 the average daily handling of petroleum in bulk amounted to more than 2500 tons (750,000 galls.), and the different grades varied from the limpid petrol and kerosene to the viscous liquid fuels and road-making flux oils, the question of pipe lines presented considerable difficulties. There were not only the practical difficulties of safeguarding contamination, but there was the chemico-engineering problem of the effect of some of the sulphur-bearing oils on tank roof plates, pumps, rods, valves, springs, and even the tanks themselves. A good deal of forethought and planning were necessary in the laying out and the construction of the pipe lines, and in the mechanical engineer's domain of boiler plant, steam mains, and the most efficient and economic methods of working. The question of type of prime mover did not arise at Thames Haven, for, having to provide steam for both refining operations and ship's use for discharging low-flash petroleum, all the pumps used were steam driven.

The works being spread over an area of nearly 200 acres, decentralisation had to be adopted rather than centralised power plant, and the 26 large B. & W. and Lancashire boilers are divided amongst eight boiler houses. A pumping installation is in close proximity to each boiler-house, the pumps employed being the direct driven steam pumps of either the single cylinder or the duplex type. In selecting the pump required the number of gallons it can deliver is calculated from bore, stroke, and piston speed. There are in use hydraulic equivalent tables for deductions per cent. of output due to friction, multiplicity of bends and elbows, length of suction and delivery lines and head of lift for suction and delivery. When, however, pumping of petroleum is the question under discussion there appears to be little published data as a guide to the engineer for either selection or manufacture of the best pump. All types have been used; the old and modern plunger pump (single, duplex or treble), the packed piston pattern (packing consisting of either soft packing or metal rings), the turbine, centrifugal and rotary pumps. Each type has its champions and detractors. The truth, however, is that there is no type of pump made which will give equally good service with all grades of petroleum products under all and any conditions.

The duplex pump, used for limpid or non-viscous petroleum products, is of the usual "Worthington" pattern, where two steam cylinders side by side have pistons connected directly to two pump plungers. A D-valve is employed and the engine works without expansion. The valve and piston strokes cross mutually at half phase, and the piston cannot then actuate the valve. In this type of pump piston No. 1 works valve No. 2, and piston No. 2 moves valve No. 1 by lever gear and rocking arms, the motion of the two pistons being alternate. The valves and pistons are so interdependent, however, that immediately steam enters one cylinder the action of the engine commences as a whole and continues, unless friction or back-pressure difficulties intervene. To enable each piston stroke to be completed before the valve reopens to steam admission, separate admission and exhaust ports are provided, which incidentally causes the imprisonment of a quantity of steam which acts as a cushion. In the tandem, compound type of duplex high-duty pumps the steam is used expansively through high-pressure and low-pressure cylinders, and again each engine works its neighbour's valves. Some makers, while not going to the length of providing a compound engine, have fixed a Meyer type cut-off valve gear, which enables the engine to work without expansion for a certain predetermined part of its strokes and expansively for the remainder. These are the mechanical details of construction of the steam end with due regard to economy and mechanical efficiency, and are adopted by all the reputable pump manufacturers. The details of the pump end of the engine are varied according to each manufacturer's experience. There is no panacea in this connection, and each case must be decided according to circumstances.

The general rules and details to be observed are that: (1) The pump rods, cylinder liners, piston rings (packing rings), valves, guards, and springs should be of brass or gunmetal. (2) Valves, guards, springs, and valve seats should be accessible. (A solid valve seat plate is preferable to separately screwed-in or pinned-in valve seats.) (3) Valve guards should be of ample strength to withstand the constant jar and should be pinned in addition to being screwed into valve seat. (4) Snuff or pet cocks should be provided both above and below delivery valve plate; and (5) the valve lift should be ample; if multiple valves are used the sum of the valve areas should be at least 25% greater than the area of the suction pipe. These pumps are recommended for such liquids as petrol, kerosene, and/or gas oils and the hydraulic tables for water pumping are a fair guide as to capacity of pump. I would suggest, however, that of two pumps capable of delivering the same quantity the pump with the longest stroke (and fewer in number per minute) is to be preferred.

As in pumping petrol, for instance, the pump gets "gassed," a delivery air vessel with relief cock should be provided with every pump. This many makers already provide, but it should be insisted on from all makers. Where the oil to be handled is very "gassy," or where long suction pipes are employed (in fact, I would recommend it in every case) a suction air vessel (similar to delivery air vessel) should be provided. This no maker supplies as an integral part of the pump, yet it insures a steady flow of the liquid to the pump, prevents "hammer," and relieves the pump from "rambling" or short stroking. In pumping petrol, especially, it is desirable that the pipes and pumps should be of ample dimensions to convey the quantity required without undue pressure. The suction pipes, if long, should be preferably larger than the inlet to the pump to avoid friction, which has a twofold undesirable quality—reduction of through-put and tendency for setting up "frictional electricity," with its companion risk of ignition. Petrol should be pumped into the bottom of a tank and not into the top, as allowing it to fall

in a cascade or shower from the top increases loss from evaporation, creates an explosive mixture above the liquid in the tank, and enhances fire risks from "frictional electricity."

The best packing for glands is "metallic" packing. "Soft" packing soon becomes hard and scores the rod, and once the rod is scored no packing will keep a gland tight. If something goes wrong with a pump the steam end should be the last to be examined, and the valve rods should not be touched. In the majority of cases the pump end is the seat of the trouble. The pump may be "gassed," a spring or guard broken, a suction valve hung up, or even a pump plunger loose or piston-rod broken.

The provision of filter gauzes on suction side of pump is an advantage, but they must be designed in duplicate boxes, where the change can be easily effected, and must provide at least 25% more unrestricted area than the suction pipe itself. Internal lubrication of steam cylinders must be efficient—particularly so where superheated steam is used—and external means of lubricating rocking arms, valve, and piston rods should be provided. The simple provision of a hole in the casting, which is so often seen on pumps for lubricating valve and rocking gear by hand, is to be deprecated, as dust and dirt get in, and this abrasive material makes a poor addition to the lubricant. These remarks apply in general to all oil pumps.

For pumping the heavier and more viscous oils we use the single-cylinder pump. These direct-acting steam pumps consist of a steam piston at one end of the piston-rod and a plunger at the other. The pumps occupy little space and have very few working parts. They have no external valve gear, and the steam cylinder is so constructed that all the steam is utilised for effective work on the piston. The slide valve operation is arranged so that there are no minute steam passages and consists of a very simple valve mechanism which is entirely enclosed.

This type of pump is in use at Thames Haven. It has the longest stroke obtainable with the least number of strokes per minute, is certain in action, and starts from any point on steam being turned on, and has no dead centre. It automatically slows down at the end of each stroke, and the valve gear and steam ports are constructed so that the piston does not strike the cover when running at excessive speed.

In pumping viscous oils the simple calculation from piston speed and size of bore and stroke will not necessarily give the number of gallons the pump is capable of delivering, because so much depends upon the viscosity of the oil, the temperature at which it is being pumped, and also upon the friction in the pipes. To recognise the difficulty in calculating the quantity of oil a given sized pump could deliver, it is well to note that at ordinary temperatures 1° F. will change the friction somewhere about 5%. The paper published by Dr. R. T. Glazebrook (J. Inst. Pet. Tech., Dec., 1915) is the most illuminating technical work on the relation of viscosity of oils to rate of flow through pipes. This matter, however, requires a good deal of further study, since in practice the velocity of even the most viscous oils exceeds considerably the experimental speed of 1·5 ft. per second employed by Dr. Glazebrook. At Thames Haven, working with viscous fuel oils, the velocity through an 8-in. pipe frequently exceeds 6 ft. per second. The difficulties of pumping viscous liquids are enhanced by the fact that even when the oil is heated before it is pumped, when long lengths of pipe lines are used for delivering, there are a series of velocities inside the pipe, the highest being in the centre and the lowest being where the oil comes in contact with the pipe itself. Therefore, in pumping viscous oils there is not only the friction of the viscous liquid on the metallic surface of the pipe, but also the internal liquid friction right through the section to the centre, and for all practical purposes the diameter of the pipe is thus reduced by the slower velocity strata nearest its circumference.

The variations in the temperatures and therefore viscosities and the friction of oils pumped through long lengths of pipe, as also the variations caused by atmospheric changes, make it practically impossible to work out correct formulæ to enable engineers to have definite data from which to select the size of pump required.

In practice, for the more viscous oils, especially those that cannot have their viscosities measured in Redwood's No. 2 viscometer at 32° F., or such oils which have a setting point of, say, 50° F. or less the following procedure is adopted: The tank in which the oil is stored is provided with steam coils and is kept at such a temperature as will reduce the viscosity sufficient to enable it to be pumped (usually between 80° and 100° F.).

The pipe-lines are in some cases enclosed in wooden boxes, with the steam pipe running alongside, but the writer does not think that this method is either economic or particularly efficient, and prefers to have a steam pipe running inside the oil pipe with the steam inlet at the furthest end away from the pump, so that the steam enters at presumably the coolest part of the pipe, and travels in an opposite direction to the oil. When the steam is employed inside an oil line great care must be taken that there is no leakage, since this would contaminate the oil and make it "wet." This is, first of all, safeguarded by providing glands to permit the steam pipe to expand freely without becoming distorted in the pipe line, and, secondly, by taper-thread sockets for the steam pipe. As a rule, all steam pipes are provided with parallel threaded sockets, and it will be realised that when a parallel-threaded socket is used for a taper-threaded pipe, it is only the last thread on the pipe that holds, and the least expansion or contraction or other movement of the steam pipe is bound to cause a leak. When, however, the threads in the sockets are tapered in the same proportion as the taper on the thread on the pipe, the whole length of the thread is closely engaged between the socket and the pipe.

So far as general remarks with regard to pumping viscous oils are concerned, it is essential that the suction and delivery pipes be of ample proportions, that a suction air vessel be used, that where filter gauzes are employed the area of such gauzes be at least 100% greater than the area of the suction pipe, and that the pump preferably have the least possible number of valves. These valves should each be of the largest possible size, and the valve seats should be so constructed that the webs do not unnecessarily break up the stream.

Since 1886, when the first British-built and owned tank steamer, the "Bakuin," landed her first bulk cargo of oil at Thames Haven, considerable experience and technical detail in handling oil in bulk have been gathered, but within the scope of this paper it would be impossible to do this sufficient justice.

On the motion of the CHAIRMAN a vote of thanks was passed to the authors for their papers, and on the motion of the HON. SECRETARY a vote of thanks was accorded to the Chairman.

Capt. GODWIN moved a vote of thanks to Mr. Talbot for his work in making the conference a success, and the HON. SECRETARY replied briefly.

The Chemical Engineering Group as a body does not hold itself responsible for the statements of fact or opinions advanced in papers and discussions at its meetings and recorded in its Proceedings.

PROPERTIES OF SATURATED STEAM.

PRESSURES.		TEMPERATURES.		LATENT HEAT. per pound.		TOTAL HEAT. per pound.		VOLUME & WEIGHT.	
Gauge.	Absolute.					from 0° C.	from 32° F.		
Inches, Mercury, Vacuum.	Lbs./sq. in.	Cent.	Fahr.	C.P.U.	B.Th.U.	C.P.U.	B.Th.U.	Cubic Feet per pound.	Pounds per cu. ft.
29.5	.21	12.2	54	588	1059	601	1081	1510	.000662
29	.45	25.0	77	582	1047	607	1093	720	.00139
28.5	.70	32.5	90	578	1039	610	1098	466	.00215
28	.94	37.6	100	575	1034	612	1102	360	.00278
27.5	1.19	42.0	108	572	1030	614	1106	272	.00368
27	1.43	45.8	114	570	1027	616	1109	237	.00422
26	1.92	51.7	125	567	1021	619	1114	179	.00559
25	2.42	56.5	134	564	1016	621	1118	146	.00685
24	2.91	60.3	140	562	1012	623	1121	122	.00820
23	3.40	63.6	146	560	1009	624	1123	105	.00952
22	3.89	66.6	152	559	1006	625	1126	93.0	.0107
21	4.38	69.4	157	557	1003	626	1128	83.0	.0120
20	4.87	71.7	161	556	1000	627	1129	75.3	.0133
19	5.36	74.0	165	554	998	628	1131	68.7	.0145
18	5.85	76.0	169	553	996	629	1133	63.5	.0157
17	6.34	78.1	173	552	994	630	1135	58.7	.0170
16	6.83	80.0	176	551	992	631	1136	54.8	.0182
15	7.32	81.7	179	550	990	632	1137	51.5	.0194
14	7.82	83.3	182	549	988	632	1138	48.5	.0206
13	8.31	84.8	184	548	987	633	1139	45.7	.0219
12	8.80	86.2	187	547	985	633	1140	43.2	.0231
10	9.78	89.0	192	546	983	635	1143	39.1	.0256
8	10.76	91.5	198	544	980	636	1144	35.7	.0280
6	11.74	93.7	201	543	977	637	1146	33.0	.0303
4	12.72	96.1	205	542	975	638	1148	30.6	.0327
2	13.71	98.0	208	540	973	638	1149	28.5	.0351
0	**14.69**	**100**	**212**	**539.3**	**971**	**639**	**1151**	**26.8**	**.0373**

Heat Units :—C.P.U.=Degree-Centigrade-Pound Unit=1.8 B. Th. U.
=0.454 kg. caloric.

B.Th. U.=Degree-Fahrenheit-Pound

Atmospheric Pressure, (Standard)=14.689 lbs. per sq. in.
=29.92″ Mercury.
=760 m/m Mercury.
=1.033 kg. per sq. cm.

Pressure :—1 lb. per sq. in. =2.037″ Mercury.
=51.7 m/m Mercury.
=0.07 kg. per sq. cm.

Volume :—1 cubic foot per pound=0.0624 cubic metre per kilo.

PRESSURES.		TEMPERATURES.		LATENT HEAT. per pound.		TOTAL HEAT. per pound.		VOLUME & WEIGHT.	
Gauge.	Absolute.					from 0° C.	from 32° F.		
Lbs. /sq. in.	Lbs. /sq. in.	Cent.	Fahr.	C.P.U.	B.Th.U.	C.P.U.	B.Th.U.	Cubic Feet per pound.	Pounds per cu. ft.
1 lb.	15.7	102.1	216	538	968	640	1152	25.1	.0398
2	16.7	103.7	218	537	967	641	1153	23.7	.0422
3	17.7	105.3	221	536	965	641	1155	22.5	.0444
5	19.7	108.5	227	534	962	643	1157	20.3	.0493
7	21.7	111.3	232	532	959	644	1159	18.6	.0538
10	24.7	115.2	239	530	954	645	1161	16.5	.0606
12	26.7	117.7	244	528	951	646	1163	15.3	.0654
15	29.7	121.0	250	526	948	647	1165	13.9	.0719
17	31.7	123.0	253	525	946	648	1167	13.0	.0769
20	34.7	126.0	259	523	942	649	1169	12.0	.0833
22	36.7	127.7	262	522	940	650	1170	11.4	.0877
25	39.7	130.5	267	520	936	651	1171	10.6	.0943
27	41.7	132.0	270	519	934	651	1173	10.1	.0990
30	44.7	134.5	274	517	931	652	1174	9.43	.106
35	49.7	138.0	280	515	927	653	1176	8.56	.117
40	54.7	141.4	286	513	923	655	1178	7.83	.128
45	59.7	144.5	292	510	918	656	1180	7.23	.138
50	64.7	147.5	297	508	914	657	1182	6.68	.150
55	69.7	150.2	302	506	911	658	1183	6.25	.160
60	74.7	152.9	307	505	909	658	1185	5.90	.169
65	79.7	155.4	312	503	905	659	1187	5.50	.182
70	84.7	157.8	316	501	903	660	1188	5.20	.192
75	89.7	160.0	320	499	898	661	1189	4.93	.203
80	94.7	162.0	324	498	896	661	1190	4.69	.213
85	99.7	164.0	327	496	894	662	1191	4.46	.224
90	104.7	166.0	331	494	890	662	1192	4.26	.235
95	109.7	167.9	334	493	887	663	1193	4.08	.245
100	114.7	169.7	337	492	886	663	1194	3.91	.256
110	124.7	173.4	344	489	880	664	1196	3.62	.276
120	134.7	176.6	350	486	875	665	1197	3.37	.297
130	144.7	179.8	356	484	871	666	1199	3.16	.316
140	154.7	182.6	361	482	868	667	1200	2.99	.334
150	164.7	185.5	366	480	864	668	1202	2.79	.358
175	189.7	192.0	378	474	853	669	1204	2.44	.410
200	214.7	197.5	387	470	846	670	1207	2.17	.461
225	239.7	203.0	397	465	837	672	1209	1.96	.510
250	264.7	208.0	406	460	829	673	1211	1.78	.562
275	289.7	212.5	414	456	822	674	1212	1.63	.613
300	314.7	216.7	422	453	815	674	1214	1.51	.662
325	339.7	220.7	429	449	809	675	1215	1.41	.709
350	364.7	225.3	438	445	801	676	1217	1.32	.758
375	389.7	228.3	443	442	796	677	1218	1.24	.806
400	414.7	231.8	449	439	790	677	1219	1.17	.855
450	464.7	238.3	461	432	778	678	1221	1.10	.909
500	514.7	244.3	472	426	768	679	1223	.95	1.053

when full

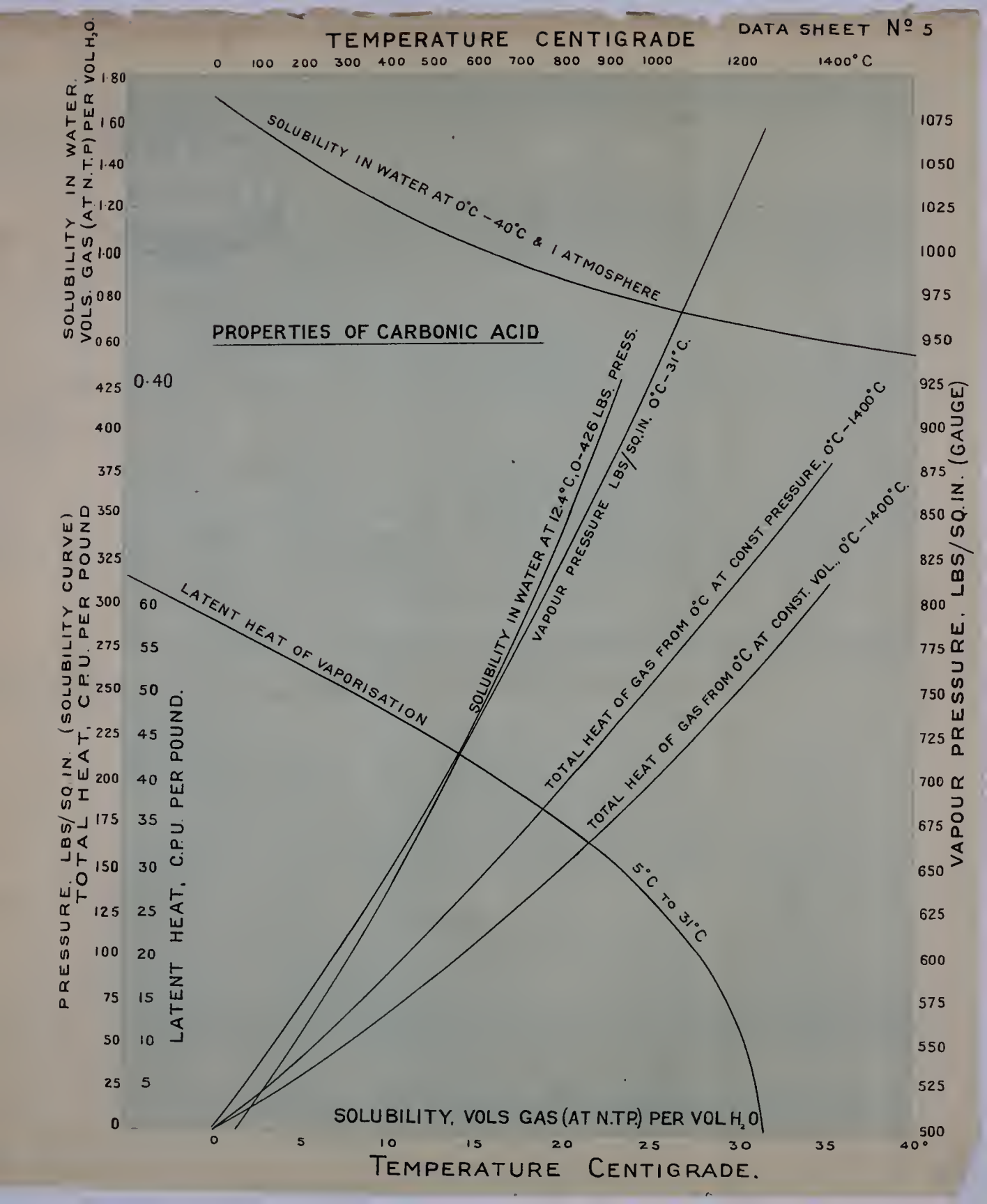
CAPACITY OF HEMISPHERICAL VESSELS IN GALLONS

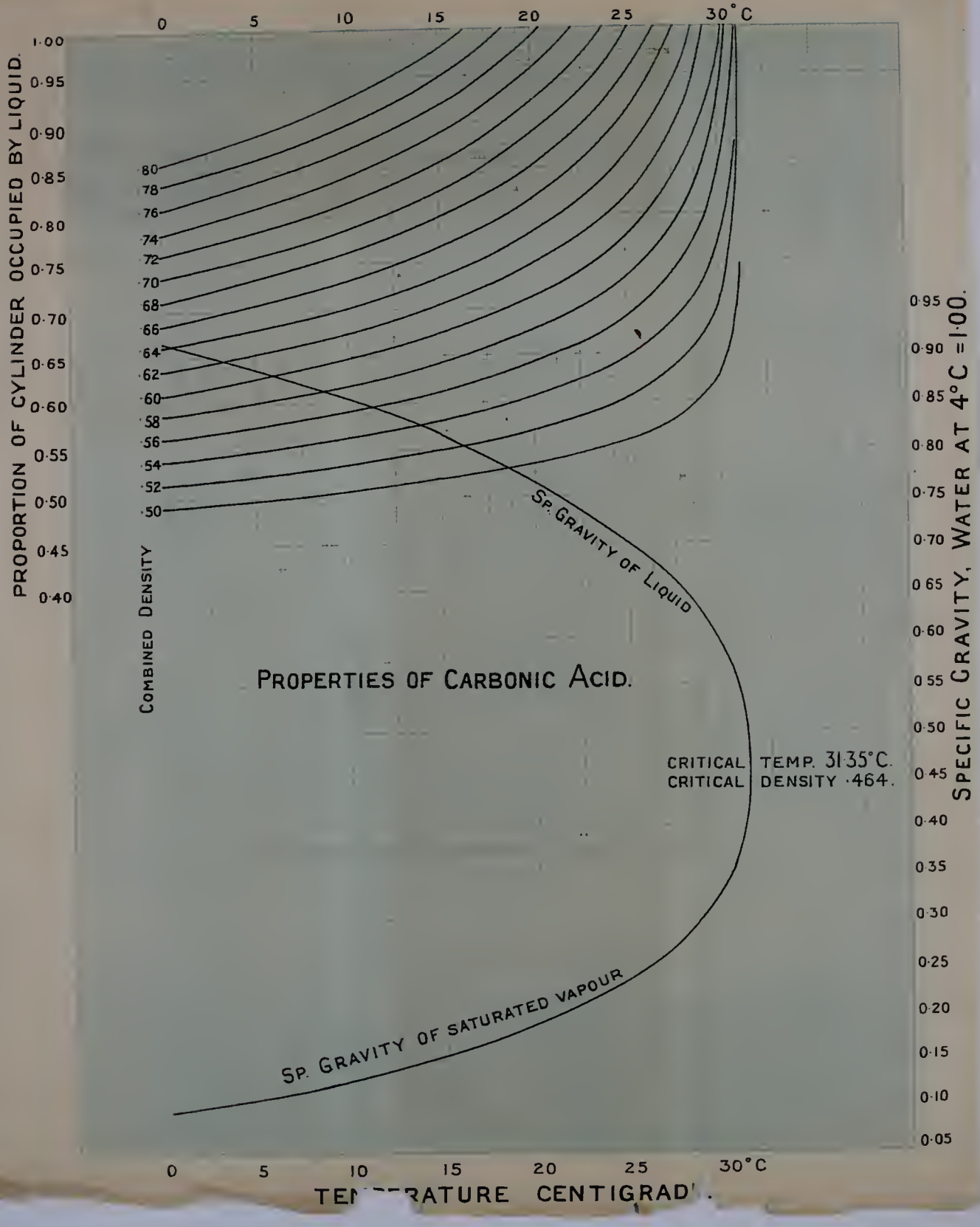
To find the capacity of larger vessels up to 15 ft diameter take the capacity of a vessel of half the diameter and multiply it by 8

IMPERIAL GALLONS

IMPERIAL GALLONS.

DIAMETER IN FEET


DATA SHEET Nº 5
TEMPERATURE CENTIGRADE
0 100 200 300 400 500 600 700 800 900 1000 1200 1400° C
SOLUBILITY IN WATER. VOLS. GAS (AT N.T.P) PER VOL H₂O.
1·80 1·60 1·40 1·20 1·00 0·80 0·60 0·40
SOLUBILITY IN WATER AT 0°C – 40°C & 1 ATMOSPHERE
PROPERTIES OF CARBONIC ACID
VAPOUR PRESSURE LBS/SQ.IN. 0°C – 31°C.
SOLUBILITY IN WATER AT 12·4°C, 0–426 LBS. PRESS.
TOTAL HEAT OF GAS FROM 0°C AT CONST PRESSURE. 0°C – 1400°C
TOTAL HEAT OF GAS FROM 0°C AT CONST. VOL., 0°C – 1400°C.
LATENT HEAT OF VAPORISATION
5°C TO 31°C
PRESSURE. LBS/SQ.IN. (SOLUBILITY CURVE) TOTAL HEAT, C.P.U. PER POUND
425 400 375 350 325 300 275 250 225 200 175 150 125 100 75 50 25 0
LATENT HEAT, C.P.U. PER POUND.
60 55 50 45 40 35 30 25 20 15 10 5
VAPOUR PRESSURE. LBS/SQ.IN. (GAUGE)
1075 1050 1025 1000 975 950 925 900 875 850 825 800 775 750 725 700 675 650 625 600 575 550 525 500
SOLUBILITY. VOLS GAS (AT N.T.P.) PER VOL H₂O
0 5 10 15 20 25 30 35 40°
TEMPERATURE CENTIGRADE.

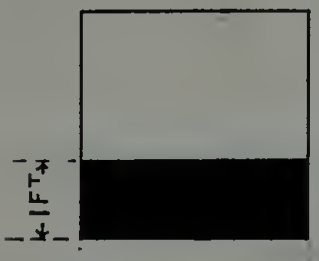

PROPORTION OF CYLINDER OCCUPIED BY LIQUID.
1·00
0·95
0·90
0·85
0·80
0·75
0·70
0·65
0·60
0·55
0·50
0·45
0·40
0
5
10
15
20
25
30° C
80
78
76
74
72
70
68
66
64
62
60
58
56
54
52
50
COMBINED DENSITY
SP. GRAVITY OF LIQUID
PROPERTIES OF CARBONIC ACID.
CRITICAL TEMP. 31·35°C.
CRITICAL DENSITY ·464.
SP. GRAVITY OF SATURATED VAPOUR
SPECIFIC GRAVITY, WATER AT 4°C = 1·00.
0·95
0·90
0·85
0·80
0·75
0·70
0·65
0·60
0·55
0·50
0·45
0·40
0·35
0·30
0·25
0·20
0·15
0·10
0·05
0
5
10
15
20
25
30°C
TEMPERATURE CENTIGRADE.

DATA SHEET Nº 2

CAPACITY PER FOOT OF DEPTH OF VERTICAL CYLINDRICAL VESSELS

IN GALLONS

TO FIND THE CAPACITY OF LARGER VESSELS UP TO 24 FT DIAMETER, TAKE THE CAPACITY OF A VESSEL OF HALF THE DIAMETER AND MULTIPLY IT BY 4



VESSELS FROM 7 TO 12 FT. (GALLONS 240 – 720)

VESSELS UP TO 7 FT. (GALLONS 0 – 240)

IMPERIAL GALLONS

720 700 680 660 640 620 600 580 560 540 520 500 480 460 440 420 400 380 360 340 320 300 280 260 240

IMPERIAL GALLONS

240 230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10

7 8 9 10 11 12

2 3 4 5 6 7

DIAMETER IN FEET

PROPERTIES OF CARBONIC ACID.

Curves prepared by Mr. J. H. West, A.M.Inst.C.E.

1 litre of pure dry CO_2 at O°C., 760 m.m. pressure, and at sea-level weighs 1.977 gram. (Greenwood)

1000 cubic feet of pure dry CO_2 at 15°C., weigh 116.9 lb. (Greenwood).

Critical temperature—31.35°C., above which no amount of pressure will liquify the gas.

The Vapour Pressure curve gives the vapour pressure in lbs. per square inch (gauge) from O°C. to 31°C. To reduce to atmospheres divide by 14.7; to reduce to kg. per cm. multiply by 0.07.

Gauge points for checking accuracy of curve :—

Pressure.	Temperature.	
573.2	5°C.	(Authority R. T. Stewart).
734.8	15°C.	
928.9	25°C.	

The Specific Heat of the gas between O°C. and 1400°C. is given in the form of two curves showing the total heat from O°C. at constant pressure and at constant volume in centigrade pound units per lb., the same values being correct for kg. calories per kg. This system is the most convenient since it is usually required to know the change of heat in a given weight of gas in passing through a given range of temperature. The specific heat at any temperature can be found from the curves by subtracting the total heat at 50° below the desired temperature from the total heat 50° above the desired temperature and dividing by 100.

Gauge points for checking accuracy of curves :—

Temperature	100°	700°	1300°C.	
Total Heat Const. Press.	20.82	170.9	347.2	C.P.U.
Total Heat Const. Vol.	15.52	130.5	282.9	C.P.U.

(Authorities, const. press. Holborn and Henning, const. vol. Crofts).

Solubility in Water. One curve shows the solubility in water at atmospheric pressure from 0°C. to 40°C. and the other the solubility in water at 12.4°C. at pressures from 0 to 426 lbs. per sq in. (gauge). In both cases the values given are the volumes of gas (measured at normal temperature and pressure) soluable in one volume of water.

Gauge points for checking accuracy of curves :—

Solubility at 1 atmosphere ;	1.424	1.019	0.665	(Authority, Greenwood).
at	5°C.	15°C.	30°C.	
Solubility at 12.4°C. ;	5.15	13.63	20.31	
at	58.7 lbs/sq. in.	205.6	352.5	

Latent Heat of Vaporisation. The curve gives this in Centigrade-pound units per pound on kg-calories per kg. from—10°C. to 30°C.

Gauge points for checking accuracy of curve :—

Temperature	7.25°C.	22°	30 6°	(Authority, Castell-Evans).
Latent Heat	50	31.8	7.26	

Specific Gravity of Liquid and Saturated Vapour. The curve gives the above from 0°C. to the critical temperature (water at 4°C. = 1.00).

Gauge points for checking accuracy of curves :—

Temperature	5°C.	15°	25°C.	(Authority, R. T. Stewart).
Sp. Gr. Liquid	.888	.814	.703	
Sp. Gr. Vapour	.113	.158	.240	

Proportion of Cylinder Volume occupied by Liquid at different temperatures, for various values of the combined density of liquid and vapour at which cylinder was charged.

These are very useful curves for those engaged in charging cylinders with liquid CO_2 for from them can be ascertained the maximum weight of CO_2 which can safely be charged into a cylinder of any given capacity, if the maximum temperature to which the cylinder is liable to be subjected is known.

By "combined density of liquid and vapour" is meant the ratio of the weight of CO_2 put into the cylinder to the weight of water at 4°C. which will completely fill the cylinder. Thus, if a given cylinder will hold 50 lbs. of water at 4°C. and 28 lbs. of CO_2 (party liquid and partly vapour) is put into it, the combined density is 28/50 = .56.

The curves show the proportion of the volume of the cylinder occupied by liquid CO_2 at various "combined densities" of charging, and various temperatures, each curve being for a different "combined density," and they further show that, as the temperature of the cylinder rises above that at which it was charged, a certain amount of vapour condenses, and the volume of liquid increases. So long as there is any vapour left, the pressure in the cylinder will be only that shown by the Vapour Pressure curve for the corresponding temperature, but immediately the cylinder becomes full of liquid the pressure rises enormously with further increase of temperature. Hence a cylinder must never be filled at such "a combined density" that it will become full of liquid at the maximum temperature to which it will be subjected, due to climate or special conditions.

If, however, a cylinder is charged at a density below the "critical density," or density at the critical temperature (.464), on raising the temperature of the cylinder above that at which it was charged the reverse effect takes place, the liquid evaporating until finally there is nothing but vapour left. Cylinders intended for tropical countries or conditions where a temperature of over 30°C. may be met with, should therefore be charged at a density not exceeding .46. (Authority, R. T. Stewart).

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CURVES PREPARED BY MR J.H. WEST A.M.INST C.E.

NOTE:- Additional copies of this sheet can be obtained from the Chemical Engineering Group on payment of a small fee.

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